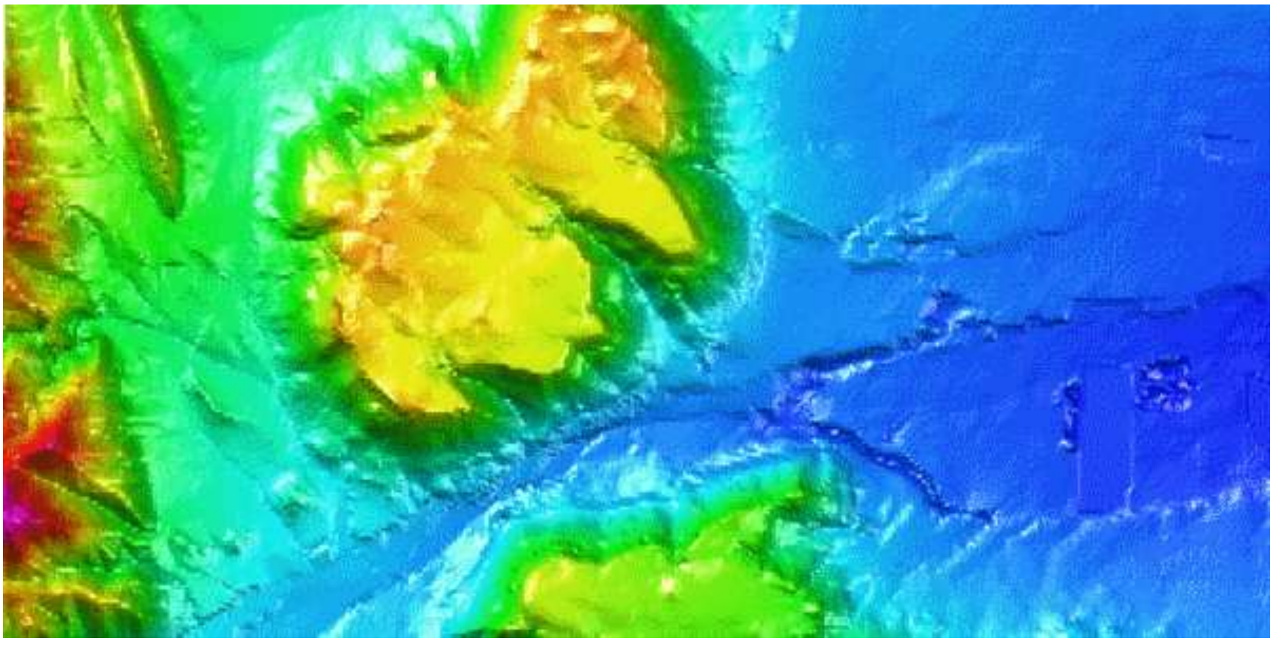
ComputationalCAD

for AutoCAD

The computational geometry add-on for AutoCAD®

USER MANUAL



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1 Welcome to ComputationalCAD

ComputationalCAD for AutoCAD is an easy to use, top-performing and robust computational geometry add-on for AutoCAD. Due to its advanced algorithms, *ComputationalCAD* for AutoCAD is perfectly suitable for **large scale computations** and **Digital Terrain Modeling** (DTM).

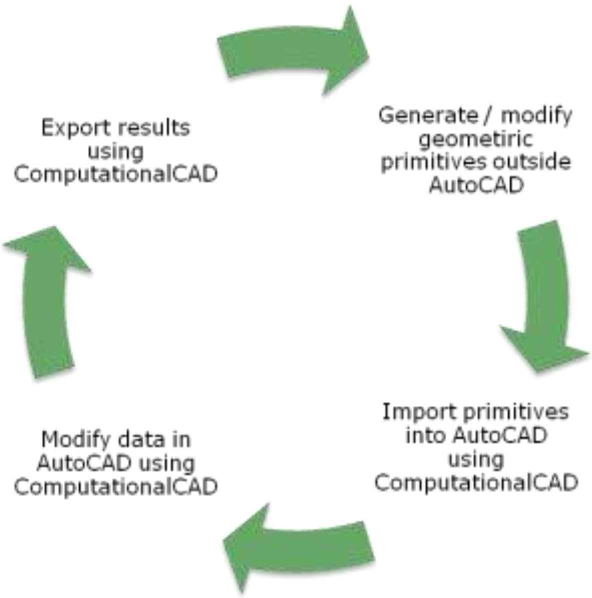
ComputationalCAD for AutoCAD focuses on efficiently processing the geometric primitives *point*, *line* / *polyline* and *3dface* in AutoCAD. Methods comprise conforming **Delaunay triangulations**, **2d** and **3d** **convex hulls**, minimum **enclosing rectangles** and **circles** and 3d **bounding boxes**. In combination with ComputationalCADs **point-on-solid** generation tool, this allows to container load 3d solids.

ComputationalCAD for AutoCAD **reconstructs surfaces** from unordered triangular or quadrilateral wireframe data.

ComputationalCAD for AutoCAD allows **generating meshes** from surfaces consisting of unordered faces, to **convert such surfaces into a solid**, to compute the **silhouette** of such surfaces and to **colorize** them.

ComputationalCAD for AutoCAD also provides a couple of useful tools, including **point-on-entity generation**, **fast polyline generation from unordered lines**, **polyline simplification**, **contour line computation**, **surface interpolation** / **projection** and **face slicing**.

ComputationalCAD for AutoCAD supports several simple but powerful plain ASCII **import and export** formats, including Microsoft Excel csv, xml and **stereolithography STL**. This enables a workflow of pre- and post-processing geometric primitives outside AutoCAD and then using *ComputationalCAD* for AutoCAD to run high-level methods within AutoCAD.



This document provides detailed help on all available commands, best practices and background information. We are also looking forward to seeing you at **www.computational-cad.com**.

2 Installation

***ComputationalCAD* for AutoCAD is available in English language**. However, it can be installed on all supported products regardless of the product language.

System requirements:

Operating systems:	Windows XP, Windows 7, Windows Vista, 32 / 64 bit.
Minimum disk space:	50MB
Minimum recommended memory:	1GB
Supported Autodesk products:	AutoCAD, AutoCAD Mechanical, AutoCAD Civil 3D and AutoCAD MAP 3D 2007 to 2012.

2.1 Install *ComputationalCAD* for AutoCAD

ComputationalCAD for AutoCAD will be installed for the current user and for all supported Autodesk products that are currently installed on your computer. To install *ComputationalCAD*, **double-click computationalcad_setup.msi and follow the instructions**. After the installation is complete, both command line commands and menues will be available in all supported Autodesk products.

If the main menu is not visible in the current workspace, type 'MENUBAR' and set its value to 1.

If the toolbar is not visible, go to Tools ➤ Toolbars ➤ COMPUTATIONALCAD ➤ ComputationalCAD (2010 or higher) or right-click in a docking region and directly select the COMPUTATIONALCAD toolbar.

You can manually load the customization file by typing "cuiload". You can browse the customization file (.cui for AutoCAD 2007-2009 or .cuix for AutoCAD 2010 and higher) in the ComputationalCAD installation folder.

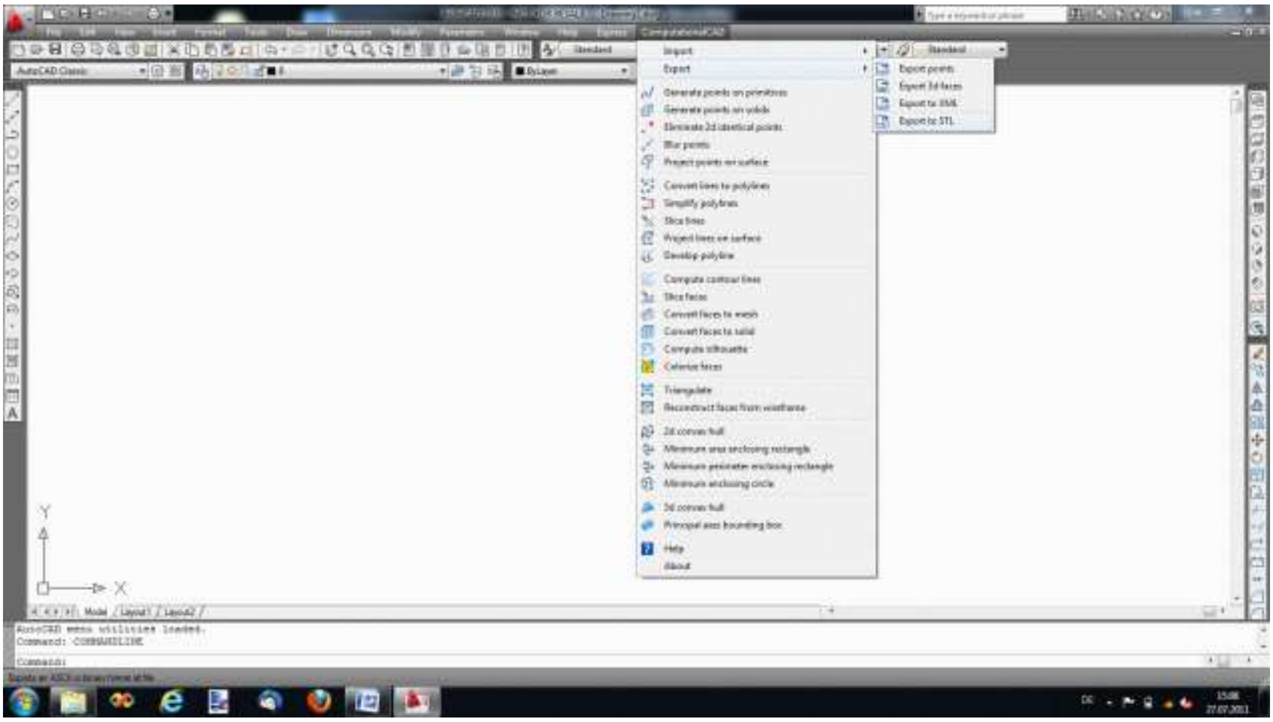


Figure 1: *ComputationalCAD* main menu

Figure 2: *ComputationalCAD* toolbar

2.2 Uninstall *ComputationalCAD* for AutoCAD

Standard procedure

1. To uninstall *ComputationalCAD* for AutoCAD, you should first unload its customization file for each installed Autodesk product. The easiest way to do this is by typing '***CC:MENU:DELETE***' in the command line.

2. Double-click on the file computationalcad_setup.msi and select the uninstall option.

Alternative proceedure

You can manually unload the ComputationalCAD menu using AutoCAD methods.

1. Type '*_cuiload*'. If the dialog is not displayed, type '*FILEDIA*' and set the value to 1.

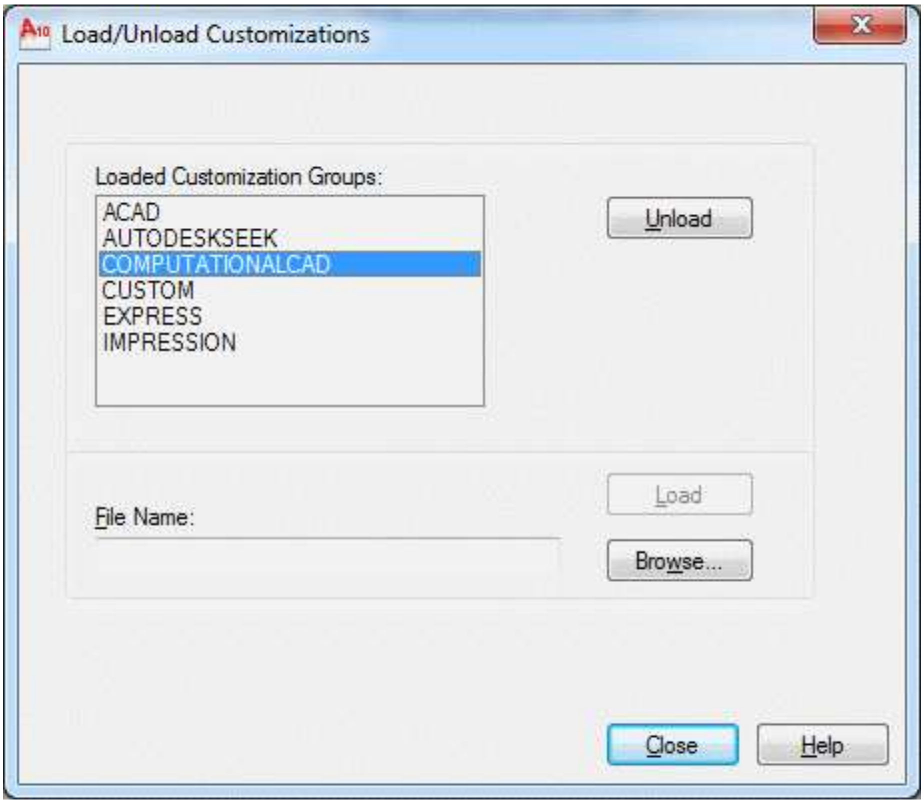


Figure 3: Unload customization file

2. Select the customization group 'COMPUTATIONALCAD' and press 'UNLOAD'. The customization group disappears.

3. Press 'CLOSE'.

4. Repeat steps 1 – 3 for each installed supported Autodesk product.

5. Double-click on the file computationalcad_setup.msi and select the uninstall option.

3 Import and export

ComputationalCAD for AutoCAD supports a couple of file formats that make it easy for standard users as well as for developers to import data into AutoCAD and to export results for further post-processing.

The ASCII xyz and 3df formats allow to import and export *point* and *3dface* data, respectively. Entity coordinates are separated by comma, semicolon or blank separators and can be imported and exported e.g. into Microsoft Excel as .csv format files.

The XML format is an easy to implement format for developers and may be a simple alternative to the more complex dxf™ format. It allows to import and export *point*, *line*, polyline and *3dface* entities with layer and color information. Developer can download a .NET class to read and write this format at www.computational-cad.com.

If the FILEDIA system variable is set to 1, dialogs are displayed. If the FILEDIA system variable is set to 0, dialog boxes are not displayed. You can still request a file dialog box to appear by entering a tilde (~) in response to the command's prompt.

3.1 The XYZ point format

Provides ASCII import and export of *point* entities.

Input format

Arbitrary comment lines start with the character 'C', all other lines are split at the specified delimiter. Empty lines are not feasible.

The first two terms (corresponding to the x and y coordinates, respectively) must be numerical. If a line only contains two (numerical) terms, the z-coordinate is set to zero. An optional third term must be numerical (the z-coordinate). Arbitrary comments can be placed after the third occurrence of the delimiter in a line. Coordinates refer to UCS.

```
C Most simple format: x and y with only one delimiter. z is set to zero.
  1.000,  2.000
C Also possible: x and y with two delimiters, z is set to zero
  1.000,  2.000,
C x, y and z using two delimiters. Comment not possible!
  1.000,  2.000,  3.000
C x, y and z, plus comment
  1.000,  2.000,  3.000, Comment goes here...
```

Example output

The first line of the file is a comment line containing the file name and file generation date. All other lines contain the x, y and z coordinates columnwise with the specified number of decimal digits (i.e. the number of decimal digits after the decimal separator) and column width. The columns are separated by the specified delimiter. Coordinates refer to UCS.

If the length of a formatted coordinate is greater than the specified column width, the respective cell is filled with the character '*'. A warning message is displayed. In this case, increase the column width or decrease the number of decimals.

Line four contains a y-coordinate greater than 9999.9999 or less than -999.9999, respectively.

```
C c:\test.pt generated 10.02.2010 15:16:10
   1.2345;  -1.2345;   0.0000;
9999.9999;-999.9999;   0.0000;
1000.0000;*********;   0.0000;
```

3.1.1 Import from a xyz format file

Read UCS *point* coordinate data from an ASCII file.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Import ➤ Import points

Command entry: CC:IO:XYZIN

Dialog

`Specify file name:`

Enter a valid file name with full path. A dialog is displayed depending on the FILEDIA settings.

Note

The coordinate delimiter is automatically detected. It must be one of comma (','), semicolon (';'), blank (' ') or a tabulator or the method fails.

3.1.2 Export to an xyz format file

Write UCS *point* coordinate data to an ASCII file.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Export ➤ Export points

Command entry: CC:IO:XYZOUT

Dialog

`Select points:`

Select the points to export.

`Specify file name:`

Enter a valid file name with full path. A dialog is displayed depending on the FILEDIA settings.
If the specified file already exists, the following dialog occurs:

`File already exists. Overwrite? [Yes, No]:`

<Yes>: The existing file will be irreversibly overwritten.
<No>: Loops back (default)

`Specify delimiter [Comma, Semicolon, Blank, Tab]:`

<Comma>:	The coordinates will be separated by comma (',')
<Semicolon>:	The coordinates will be separated by semicolon (';') (default)
<Blank>:	The coordinates will be separated by blank (' ')
<Tab>:	The coordinates will be separated by a tabulator

`Specify column width or [Fit]:`

Enter the width of the column for each coordinate or 'F' for optimal width. Expects an integer value between 1 and 256 or 'F'. Default is <9>.

`Specify number of decimal digits or [Float]:`

Enter the number of decimal digits after the decimal separator of each coordinate or 'F' for maximum precision. Expects an integer value between 1 and 16 or ' F'. Default is <4>.

Note

Use the XML format to provide layer and color information.

3.2 The 3d face format

Provides ASCII import and export of *3dface* entities with layer information.

Input format

Arbitrary comment lines start with the character 'C', all other lines are split at the specified delimiter. Empty lines are not feasible.

The first term must be the valid AutoCAD layer name of the 3d face. The UCS x, y and z coordinates of each vertex follow. Note that an AutoCAD *3dface* entity has always four vertices. To describe a triangular face, the third and fourth vertex must be identical.

```
C Arbitrary comments go after 'C'
C Format: Layername, x1, y1, z1, x2, y2, z2, x3, y3, z3, x4, y4, z4
tri,  1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 7.0, 8.0, 9.0,
quad, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0,10.0,11.0,12.0,
```

Example output

The first line of the file is a comment line containing the file name and file generation date. The second line is a comment line containing format information. All other lines are data lines containing the x, y and z coordinates of all four vertices columnwise using the specified number of decimal digits (i.e. the number of decimal digits after the decimal separator) and column width. The columns are separated by the specified delimiter. Coordinates refer to UCS.

If the length of a formatted coordinate is greater than the specified column width, the respective cell is filled with the character '*'. A warning message is displayed. In this case, increase the column width or decrease the number of decimals.

```
C c:\tmp\faces.3df generated 01.09.2010 13:55:59
C Format: Layername, x1, y1, z1, x2, y2, z2, x3, y3, z3, x4, y4, z4
tri,  1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 7.0, 8.0, 9.0,
quad, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0,10.0,11.0,12.0,
```

3.2.1 Import a 3d face format file

Read *3dface* UCS coordinate data with layer information from an ASCII file.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Import ➤ Import 3d faces

Command entry: CC:IO:3DFIN

Dialog

`Specify file name:`

Enter a valid file name with full path. A dialog is displayed depending on the FILEDIA settings.

Note

The coordinate delimiter is automatically detected. It must be one of comma (','), semicolon (';'), blank (' ') or a tabulator or the method fails.

3.2.2 Export to a 3d face format file

Write *3dface* UCS coordinate data with layer information to an ASCII file.

Access methods

Toolbar: 3df

Menu: ComputationalCAD ➤ Export ➤ Export 3d faces

Command entry: CC:IO:3DFOUT

Dialog

`Select faces:`

Select the 3d faces to write in the file.

`Specify file name:`

Enter a valid file name with full path. A dialog is displayed depending on the FILEDIA settings. .

If the specified file already exists, the following dialog occurs:

`File already exists. Overwrite? [Yes, No]:`

<Yes>: The existing file will be irreversibly overwritten.

<No>: Loops back (default)

`Specify delimiter [Comma, Semicolon, Blank, Tab]:`

<Comma>: The coordinates will be separated by comma (',')

<Semicolon>: The coordinates will be separated by semicolon (';') (default)

<Blank>: The coordinates will be separated by blank (' ')

<Tab>: The coordinates will be separated by a tabulator

`Specify column width or [Fit]:`

Enter the width of the column for each coordinate or ‘F’ for optimal fit. Expects an integer value between 1 and 256 or ‘F’. Default is <9>.

`Specify number of decimal digits or [Float]:`

Enter the number of decimal digits after the decimal separator of each coordinate or ‘F’ for floating point precision. Expects an integer value between 1 and 16 or ‘F’. Default is <4>.

Note

Use the XML format to provide layer and color information.

3.3 The XML format

The XML format supports *point*, *line*, *polyline* and *3dface* entities, each with color index and layer name. Developer can download a .NET class with XML serializer / deserializer for this format at www.computational-cad.com.

Example input and output

The XML scheme for *point*, *line*, *polyline* and *3dface* entities is given below. Coordinates refer to UCS. The polyline export supports 2d and 3d polylines. Imported polylines are always generated as 3d polyline entities.

```xml
<?xml version="1.0" encoding="utf-8"?>
<EntityList xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  <Points>
    <Point>
      <LayerName></LayerName>
      <ColorIndex></ColorIndex>
      <X></X>
      <Y></Y>
      <Z></Z>
    </Point>
  </Points>
  <Lines>
    <Line>
      <LayerName></LayerName>
      <ColorIndex></ColorIndex>
      <StartVertex>
        <X></X>
        <Y></Y>
        <Z></Z>
      </StartVertex>
      <EndVertex>
        <X></X>
        <Y></Y>
        <Z></Z>
      </EndVertex>
    </Line>
  </Lines>
  <Polylines>
    <PolyLine>
      <LayerName></LayerName>
      <ColorIndex></ColorIndex>
      <Vertices>
        <Vertex>
          <X></X>
          <Y></Y>
          <Z></Z>
        </Vertex>
        <Vertex>
          <X></X>
```

```
          <Y></Y>
          <Z></Z>
        </Vertex>
        <Vertex>
          <X></X>
          <Y></Y>
          <Z></Z>
        </Vertex>
      </Vertices>
    </PolyLine>
  </Polylines>
  <Faces>
    <Face>
      <LayerName></LayerName>
      <ColorIndex></ColorIndex>
      <Vertex1>
        <X></X>
        <Y></Y>
        <Z></Z>
      </Vertex1>
      <Vertex2>
        <X></X>
        <Y></Y>
        <Z></Z>
      </Vertex2>
      <Vertex3>
        <X></X>
        <Y></Y>
        <Z></Z>
      </Vertex3>
      <Vertex4>
        <X></X>
        <Y></Y>
        <Z></Z>
      </Vertex4>
    </Face>
  </Faces>
</EntityList>
```

3.3.1 Import a XML entity format file

Read UCS *point*, *line*, *polyline* and *3dface* data with layer and color information from an XML file.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Import ➤ Import xml

Command entry: CC:IO:XMLIN

Dialog

`Specify file name:`

Enter a valid file name with full path. A dialog is displayed depending on the FILEDIA settings. .

Note

Polylines will be inserted as 3d polyline entities.

3.3.2 Export to a XML entity format file

Write UCS *point*, *line*, *polyline* and *3dface* data with layer and color information to an XML file.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Export ➤ Export xml

Command entry: CC:IO:XMLOUT

Dialog

`Select objects:`

Select the point, line, polyline and 3d face objects to write to the file.

`Specify file name:`

Enter a valid file name with full path. A dialog is displayed depending on the FILEDIA settings.

If the specified file already exists, the following dialog occurs:

`File already exists. Overwrite? [Yes, No]:`

<Yes>: The existing file will be irreversibly overwritten.

<No>: Loops back (default)

Note

Polylines can be 2d or 3d polylines. However, polylines will always be imported as 3d polyline entities.

3.4 The STL format

Provides import and export of ASCII and binary STL files.

Format

STL is a file format native to the stereolithography CAD software created by 3D Systems. This file format is it is widely used for rapid prototyping and computer-aided manufacturing. STL files describe only the surface geometry of a three dimensional object without any representation of color, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact. Both formats are non-proprietary and can be studied in detail e.g. at http://en.wikipedia.org/wiki/STL_(file_format).

3.4.1 Import a STL format file

Read 3dfaces defined in an ASCII or binary format STL file.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Import ➤ Import STL

Command entry: CC:IO:STLIN

Dialog for ASCII format

`Insert on layer [Current/specify Name/by STL] <by STL>:`

Specify the layer the faces will be inserted.

<Current>:	The points will lie on the current layer.
<by STL>:	The points will lie on a layer named by the solid name in the ASCII STL file header. If the layer does not exist, it will be created. (Default)
<specify Name>:	The following dialog is displayed:

`Specify layer name:`

Enter the name of the layer the points shall be added to. If the layer does not exist, it will be generated.

Dialog for binary format

`Insert on layer [Current/specify Name] <Current>:`

Specify the layer the faces will be inserted.

<Current>:	The points will lie on the current layer. (Default)
<specify Name>:	The following dialog is displayed:

`Specify layer name:`

Enter the name of the layer the points shall be added to. If the layer does not exist, it will be generated.

Note

ASCII or binary format STL will be detected automatically.

Some elder STL formats may only accept positive coordinates. ComputationalCAD for AutoCAD accepts both positive and negative XYZ coordinates. However, you will be warned if negative coordinates have been detected during read.

In both ASCII and binary versions of STL, the facet normal should be a unit vector pointing outwards from the solid object (“right hand rule”). ComputationalCAD for AutoCAD ignores facet normal vectors. However, you will be warned if inconsistent facet normals have been detected.

In binary STL, ComputationalCAD for AutoCAD accepts color information in VisCAM / SolidView format (RGB information in the attribute byte count, see http://en.wikipedia.org/wiki/STL_(file_format)).

Coordinates always refer to the WCS.

Example ASCII STL format command line output

```
STL solid name                : surface
Number of triangles read      : 126523
Number of degenerate triangles: 0
Has negative coordinates      : False
Inconsistent facet normals    : True
Solid inserted on layer surface
```

Example binary STL format command line output

```
Number of triangles read      : 126523
Number of degenerate triangles: 0
Has negative coordinates      : False
Inconsistent facet normals    : True
File contains colors          : True
```

3.4.2 Export a STL format file

Writes 3dfaces in an ASCII or binary format STL file.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Export ➤ Export to STL

Command entry: CC:IO:STLOUT

Dialog for ASCII format

Specify STL type [Binary/Ascii] <Binary>:

Specify the STL format type.
<Binary>: Output format will be STL binary. (Default)
<ASCII >: Output format will be STL ASCII.

Specify STL solid name <0>:

Specify the name of the solid. Default is the layer name of the first selected face.

Dialog for binary format

Specify STL type [Binary/Ascii] <Binary>:

Specify the STL format type.
<Binary>: Output format will be STL binary. (Default)
<ASCII >: Output format will be STL ASCII.

Note

Some elder STL formats may only accept positive coordinates. ComputationalCAD for AutoCAD accepts both positive and negative XYZ coordinates to write. However, you will be warned if negative coordinates have been detected during write.

ComputationalCAD for AutoCAD, the facet normal is always a unit vector pointing outwards from the solid object (“right hand rule”). ComputationalCAD for AutoCAD cant not write degenerate faces (i.e faces with collinear or identical vertices where a face normal can not be computed). You will be warned if inconsistent facet normals have been detected.

In binaly format STL, ComputationalCAD for AutoCAD automatically writes color information in VisCAM / SolidView format (RGB information in the attribute byte count, see http://en.wikipedia.org/wiki/STL_(file_format)).

Coordinates always refer to the WCS.

Example command line output

```
Number of triangles written   : 126401
Number of degenerate triangles: 0
Has negative coordinates      : False
STL file in binary format written to
C:\Users\Christian\Documents\entities_col.stl
```

4 Handling point primitives

ComputationalCAD for AutoCAD provides a couple of methods to generate and modify point data to generate input for other methods. Available methods allow to

- **reengineer point data** from a surface consisting of *3dface* entities,
- **generate point data from *text*** entities,
- **reduce the amount of point data,**
- **generate point data by subdivision** of *spline*, *line*, *polyline*, *circle* or *arc* entities,
- **eliminate duplicate points** with identical xy-coordinates in UCS within a specified range,
- **blur the xy-coordinates of points** in UCS,
- **project points onto a surface** consisting of *3dface* entities.

Influence the appearance of points by setting the AutoCAD _*ddptype* value.

4.1 Generate points on primitives

Generate equidistant points on various AutoCAD primitives.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Generate points on primitives

Command entry: CC:POINTS:GENERATE

Dialog

`Select entity type <Lines, Texts, Circles, Ellipses, Arcs, Splines, 3dFaces, Polylines, ALL>:`

<Lines>:	Generates equidistant points on lines.
<Texts>:	Reads the text property of a single line text and generates a point at the insertion point of the text if the text is numerical.
<Circles>:	Generates equidistant points on the perimeter of circles.
<Ellipses>:	Generates equidistant points on the perimeter of ellipses.
<Arcs>:	Generates equidistant points on the perimeter of arcs.
<Splines>:	Generates equidistant points on splines.
<3dFaces>:	Generates points at the vertices of 3d faces.
<Polylines>:	Generates equidistant points on linear 2d and 3d polylines.
<ALL>:	Generates points on all available entities. (default)

For all entity types except <Texts> and <3dFace>, the following dialog will be displayed:

`Enter maximum subdivision distance or 0 for no subdivision:`

Enter the maximum distance between two equidistant points generated on the specified entities. Expects a value greater than 0. Default is <1>.

`Insert on layer [Current/specify Name] :`

<Current>:	The points will lie on the current layer. (Default)
<specify Name>:	The following dialog is displayed:

`Specify layer name:`

Enter the name of the layer the points shall be added to. If the layer does not exist, it will be generated.

`Insert as block? <Yes, No> :`

<Yes>: The following dialog is displayed:

`Specify block name:`

Enter the name of the block the points shall be added to. If the block does not exist, it will be generated.

<No>: The points will be inserted in the model space. (Default)

Summary

On each entity, equidistant points are generated so that the distance between two points is not greater than the specified subdivision distance. Duplicate points will be eliminated. A zero subdivision distance does not affect <Texts> and <3dFaces> entities. For all other entities, it has the following effect:

`<Lines>` and `<Splines>`: points are generates at start and end points only.

`<Circles>`, `<Ellipses>` and `<Arcs>`: points are generated at the center points only.

`<Polylines>`: points are generates at each vertex of a polyline.

Example

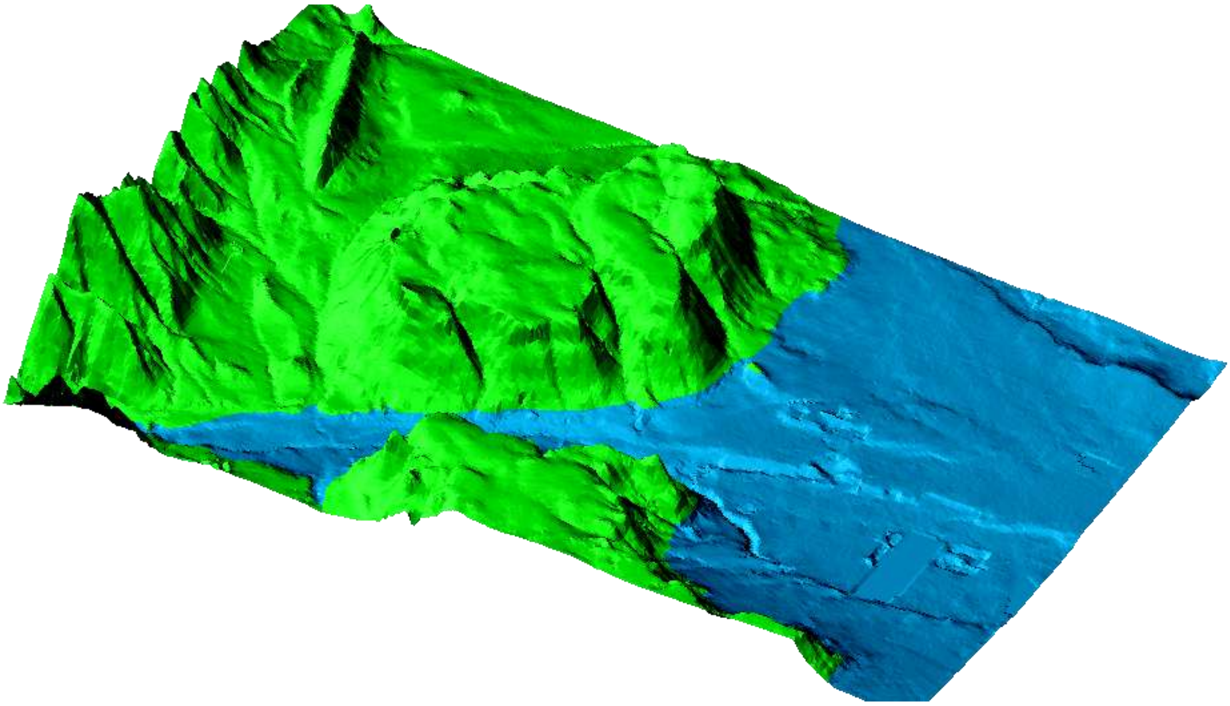


Figure 4: 107k 3dface entities

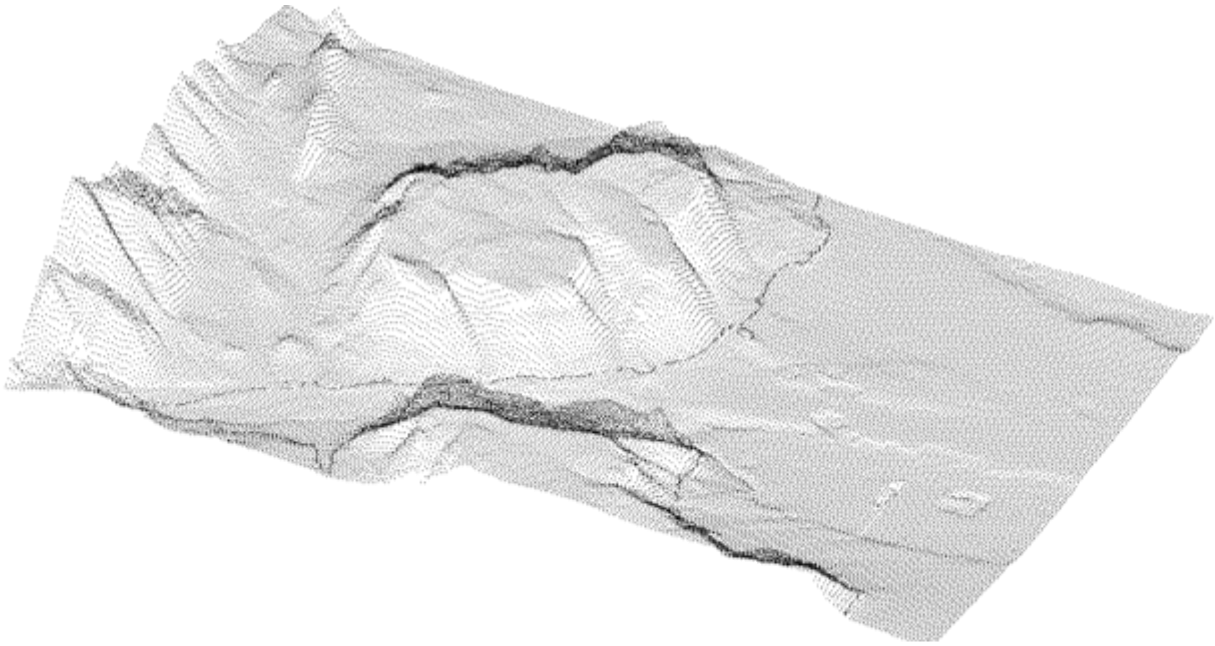


Figure 5: 54k corner vertices of above faces generated using the Generate points command

4.2 Generate points on solids

Generate points on AutoCAD Solid3D entities. **This method is only available for AutoCAD versions 2010 or higher.**

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Generate points on solids

Command entry: CC:SOLIDS:TESSELATE

Dialog

`Select 3d solids:`

Select one or more Solid3d entities.

`Specify maximum node spacing:`

Enter the maximum distance between two points generated on the solid(s). Expects a value greater than 0. Default is 1/100 of the maximum diagonal of the geometric extends of all selected solids.

`Insert on layer [Current/specify Name] :`

<Current>: The points will lie on the current layer. (Default)

<specify Name>: The following dialog is displayed:

> **`Specify layer name:`**
>
> Enter the name of the layer the points shall be added to. If the layer does not exist, it will be generated.

`Insert as block? <Yes, No> :`

<Yes>: The following dialog is displayed:

> **`Specify block name:`**
>
> Enter the name of the block the points shall be added to. If the block does not exist, it will be generated.

<No>: The points will be inserted in the model space. (default)

Summary

The solid may be arbitrary complex. The generated points are the corner vertices of the tessellation of the solid. Due to AutoCAD internals, the actual distance between two points on a solid may be significantly smaller than the maximum node spacing.

Example

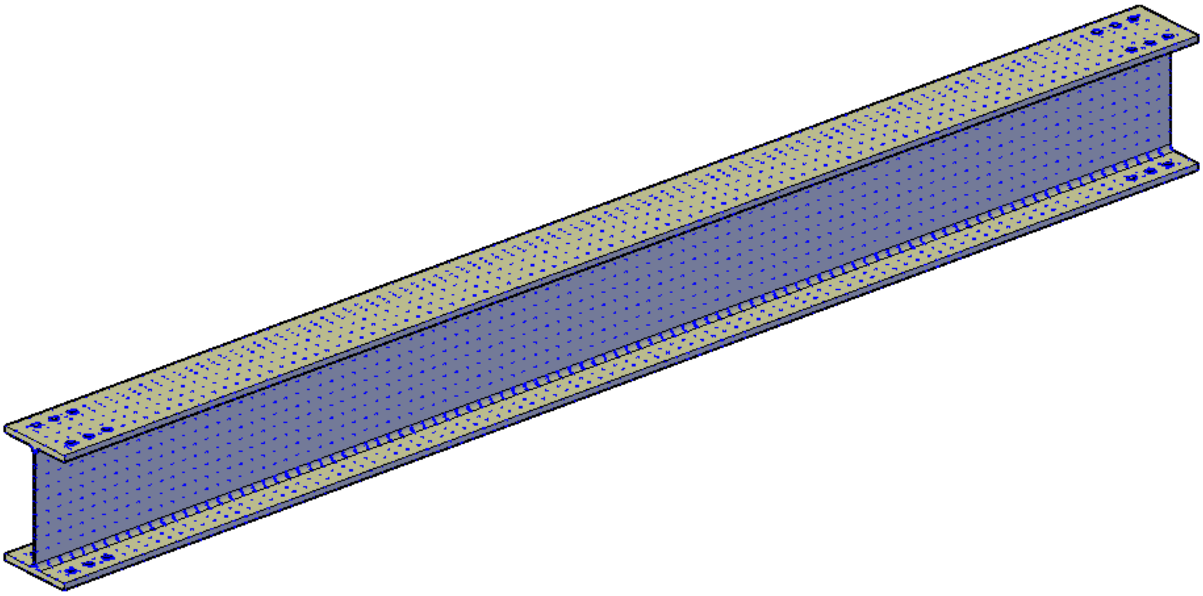


Figure 6: 9008 points generated on an I-beam with holes

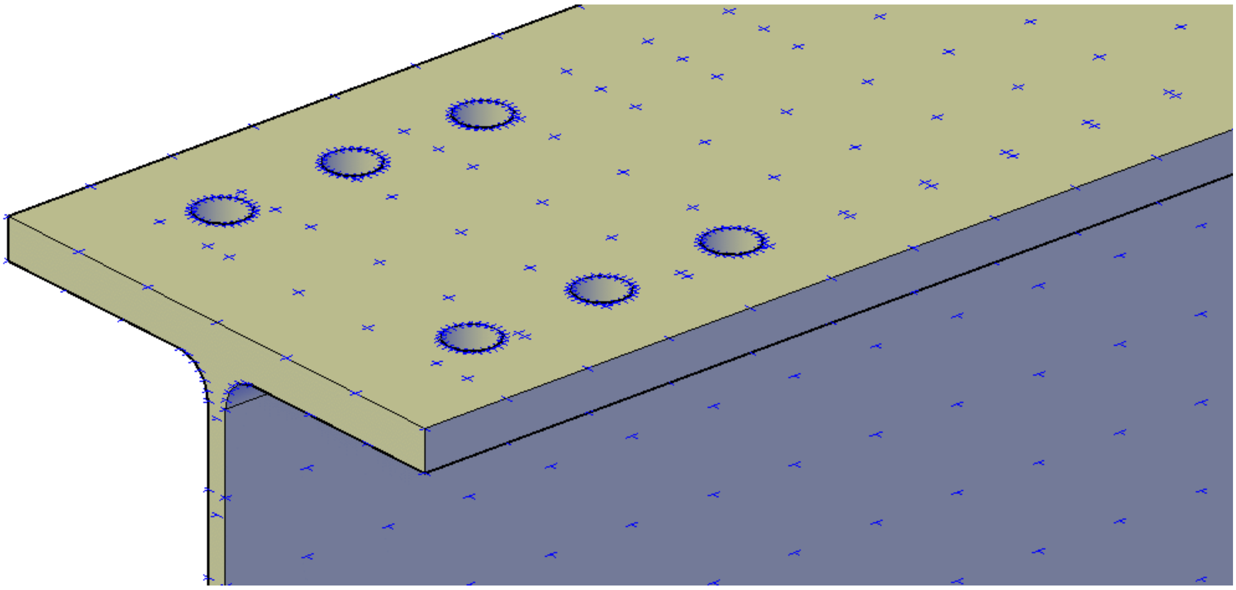


Figure 7: Detail view of points on I-beam

4.3 Eliminate duplicate points in UCS xy plane

Eliminate duplicate points with identical x and y coordinates in UCS.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Eliminate 2d identical points

Command entry: CC:POINTS:ELIM2D

Dialog

`Select points:`

Select the points to eliminate duplicates from.

`Specify snap radius:`

Enter the snap radius. Expects a value greater or equal 0. Default is <0>.

`Point to keep [Highest/Lowest]:`

<Highest>:	The point with the highest z-coordinate within the snap radius is kept. (default)
<Lowest>:	The point with the lowest z-coordinate within the snap radius is kept.

Summary

If the UCS z-coordinate of point p_1 is greater than the z-coordinate of point p_2, p_2 will be eliminated if <Highest> was specified. Otherwise, p_1 will be eliminated. If the UCS z-coordinates of both points are identical, any of the points will be eliminated. All coordinates refer to UCS.

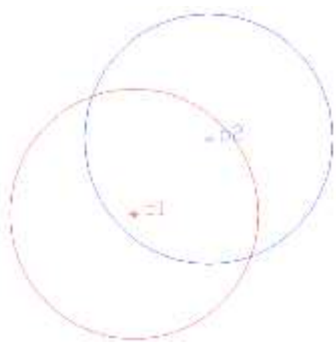


Figure 8: Two points and respective snap circles

Use the native AutoCAD command *overkill* to eliminate identical 3d points.

Example

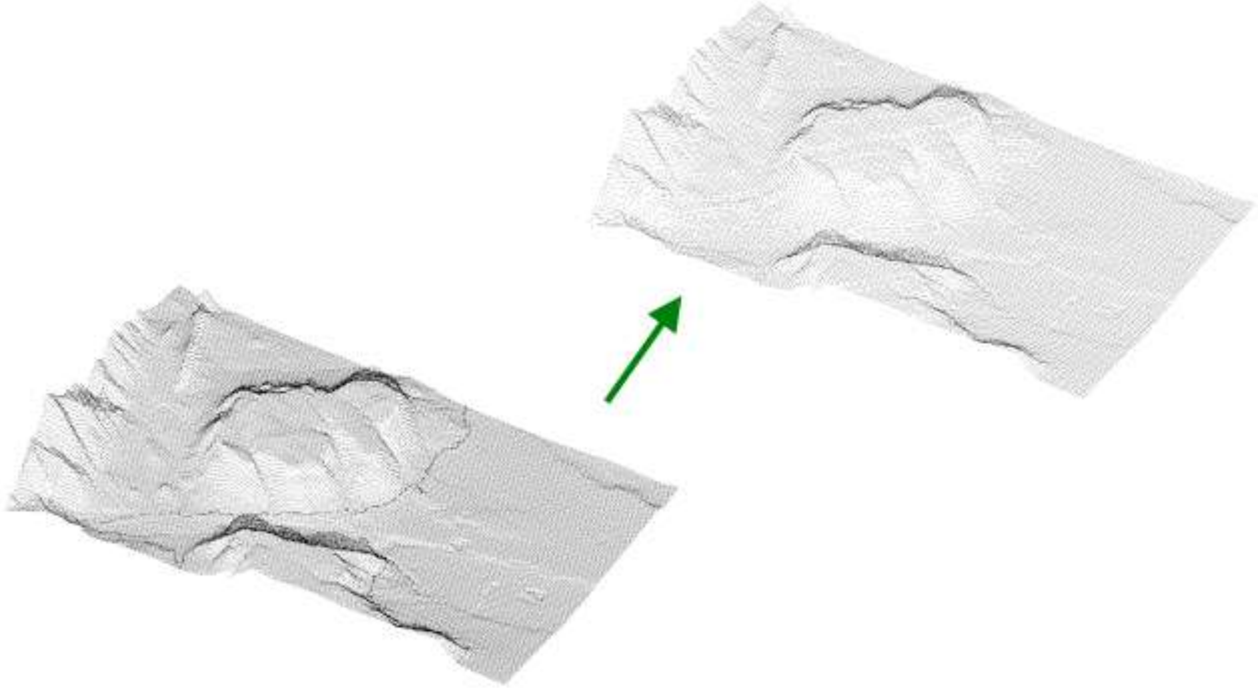
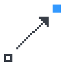


Figure 9: 54k vertices reduced to 28k vertices using the Elim2d command

4.4 Blur points in UCS xy plane

Blur the x and y coordinates of a point in UCS.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Blur points

Command entry: CC:POINTS:BLUR

Dialog

`Select points:`

Select the points to blur.

`Specify blur radius:`

Enter the blur radius. Expects a value greater than 0. Default is 1e-9.

Summary

This command randomly offsets the UCS x and y coordinates within the specified blur radius. Blurring rastered point data creates biunique data for a triangulation.

Example

Figure 10: 85 points on an equidistant raster (black) and blurred points (blue)

4.5 Project points onto a surface

Project points onto a surface consisting of 3dface entities.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Project points

Command entry: CC:POINTS:PROJECT

Dialog

`Select faces:`

Select the 3dfaces defining the surface

`Select points:`

Select the points to project.

`Specify projection direction [X/Y/Z/Ucs/2Points]:`

Select the projection direction.

<X>:	The points are projected in global X-direction
<Y>:	The points are projected in global Y-direction.
<Z>:	The points are projected in global Z-direction. (default)
<Ucs>:	The points are projected in UCS z-direction.
<2Points>:	The points are projected in a user defined projection direction. The following dialog occurs:

`Specify first point`

Select the first point of the projection direction.

`Specify second point`

Select the second point of the projection direction.

`Insert on layer [Current/by Face/by Point]:`

Select the layer assignment for the projected points.

<Current>:	The projected points will be inserted on the current layer.
<by Face>:	The projected points will be inserted on the layer of the 3dface the point was projected onto. (default)
<by Point>:	The projected points will be inserted on the layer of the original point.

`Delete original points [Yes/No]:`

Specify if the original points shall be deleted.

<Yes>:	The original points will be erased.
<No>:	The original points will not be erased. (default)

`Point to keep [Highest/Lowest]:`

<Highest>:	The point with the highest z-coordinate is kept. (default)
<Lowest>:	The point with the lowest z-coordinate is kept.

Example

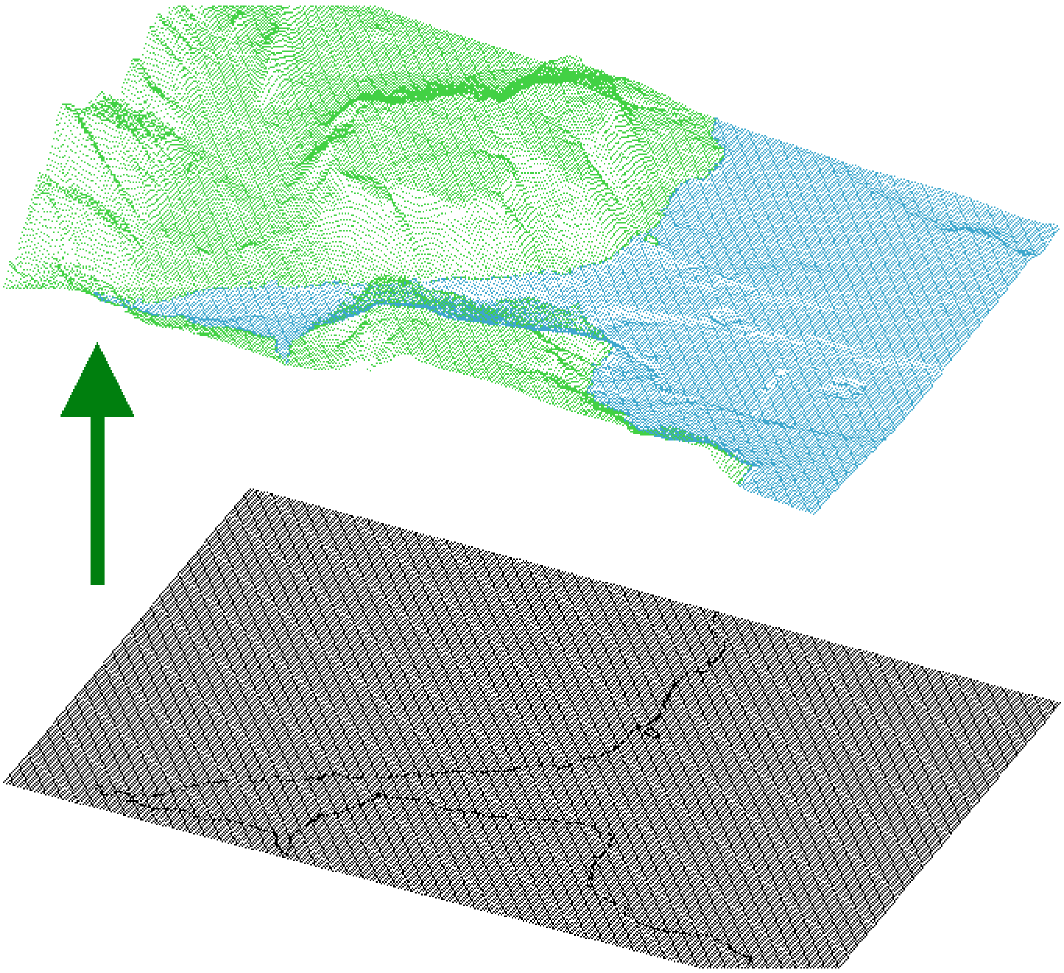


Figure 11: 54k vertices (black) projected onto a surface consisting of 104k faces (not shown for clarity)

5 Handling line primitives

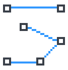
ComputationalCAD for AutoCAD provides several methods to process *line* entities. Available methods allow to

- **generate polylines from unordered lines**
- **simplify polylines** by reducing the number of vertices
- **slice multiple lines** on a 3d slicing plane
- **project lines** onto a surface consisting of 3dface entities.

5.1 Generate polylines from a set of unordered lines

Generate 3d polylines from a set of unordered lines.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Convert lines to polylines

Command entry: CC:LINES:TOPLINE

Dialog

`Select lines:`

Select the lines to convert into 3d polylines

`Specify number of relevant decimal digits:`

Specify the number of relevant decimal digits after the decimal separator. All coordinates will be rounded to the specified value. Expects an integer value between 0 and 12. Default is <8>.

`Eliminate zero length segments [Yes/No]:`

With r being the number of relevant decimal digits, specify if segments with a length smaller then 10^{-r} shall be eliminated.

<Yes>:	Polyline segments shorter than 10^{-r} will be eliminated. (default)
<No>:	The polyline will contain all segments.

`Delete original lines [Yes/No]:`

Specify if the original lines shall be deleted.

<Yes>:	The original lines will be deleted.
<No>:	The original lines will not be deleted. (default)

Summary

The command converts all selected lines into POLY3D entities and **joins adjoining lines** if

1. the lines lie on the same layer
2. the lines have the same color
3. the lines have a common start or endpoint, respectively, within the precision specified.

The number of relevant decimal digits specifies how many decimal digits after the decimal separator have to be identical in order to consider start or end vertex, respectively, of two adjoining line segments to be identical. The coordinates of all vertices will be rounded to the specified value.
Branching is not feasible for AutoCAD polyline objects. The layer and color properties of incident lines are used to decide which lines to connect at a branching point. However, if multiple options exist, the result will be arbitrary.

Example

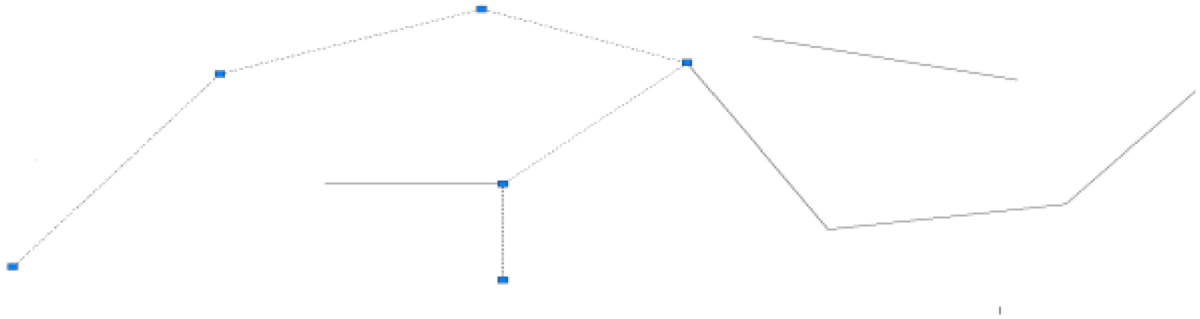


Figure 12: Four 3d polylines (one highlighted), generated from 10 line segments. Since all lines have the same layer and color properties, the behavior at the branching points is arbitrary.

Command line prompt:

```
Number of segments added         : 10
Number of zero-length segments   : 0
Number of polylines generated    : 4
```

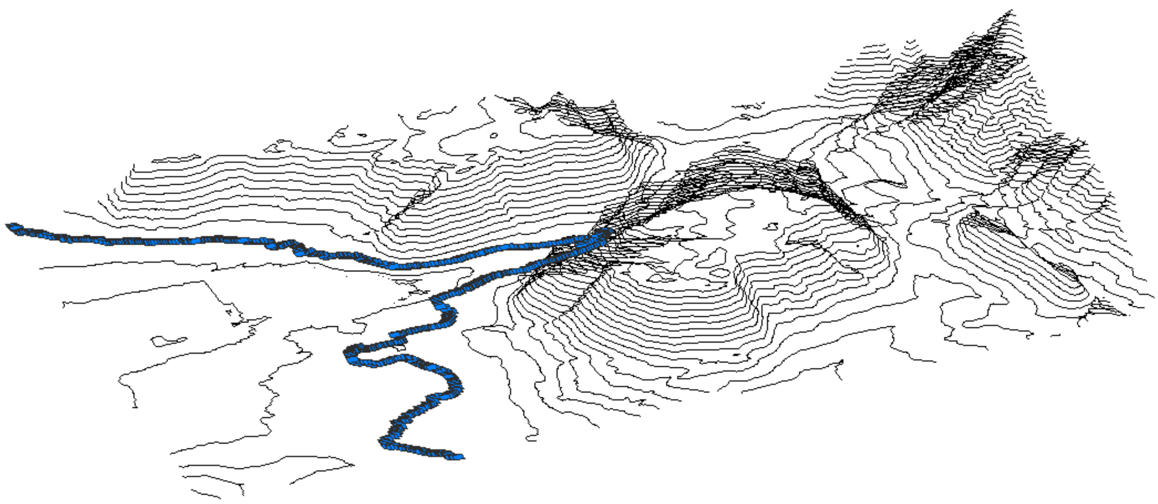


Figure 13: 201 polylines (one selected), generated at once from 35330 individual (contour) line segments

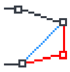
Command line prompt:

```
Number of segments added         : 35330
Number of zero-length segments   : 0
Number of polylines generated    : 201
```

5.2 Simplify polylines

Reduce the number of AutoCAD 3d polyline vertices so that the maximum spatial distance between any points on the original polyline to the simplified polyline is smaller than specified.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Simplify polylines

Command entry: CC:LINES:SIMPLIFYPLINE

Dialog

`Select polylines:`

Select the polylines to simplify. This may be 2d or 3d polylines.

`Specify epsilon range:`

Specify the maximum spatial distance between any point on the original polyline to the simplified polyline. Expects a positive value or zero.

`Keep original polylines [Yes/No]:`

Specify if the original polylines shall be deleted.

<Yes>:	The original lines will not be deleted. (default)
<No>:	The original lines will be deleted.

Summary

The command creates a new 3d polyline sharing start and end vertex with the original polyline. Successively going through the intermediate vertices of the original polyline, an intermediate vertex will only be added to the simplified polyline if necessary to ensure that the maximum spatial distance between any points on the original polyline to the simplified polyline is smaller than specified.

Example

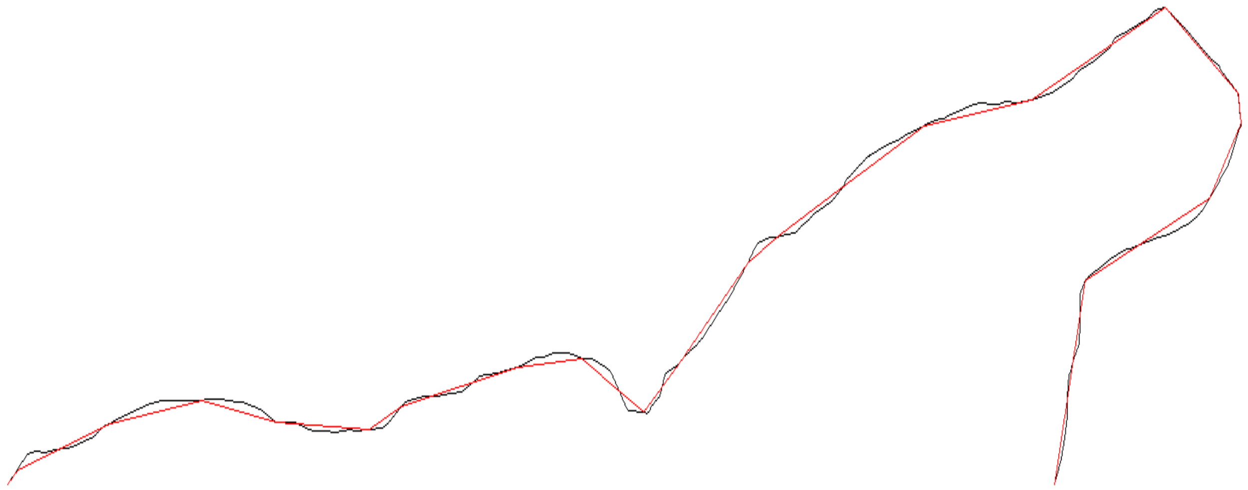


Figure 14:203 vertices in one polyline (black) reduced to 23 vertices in a simplified polyline (red)

Command line prompt:

```
Number of vertices before    : 203
Number of vertices after     : 23
Number of polylines processed: 1
Number of polylines failed   : 0
```

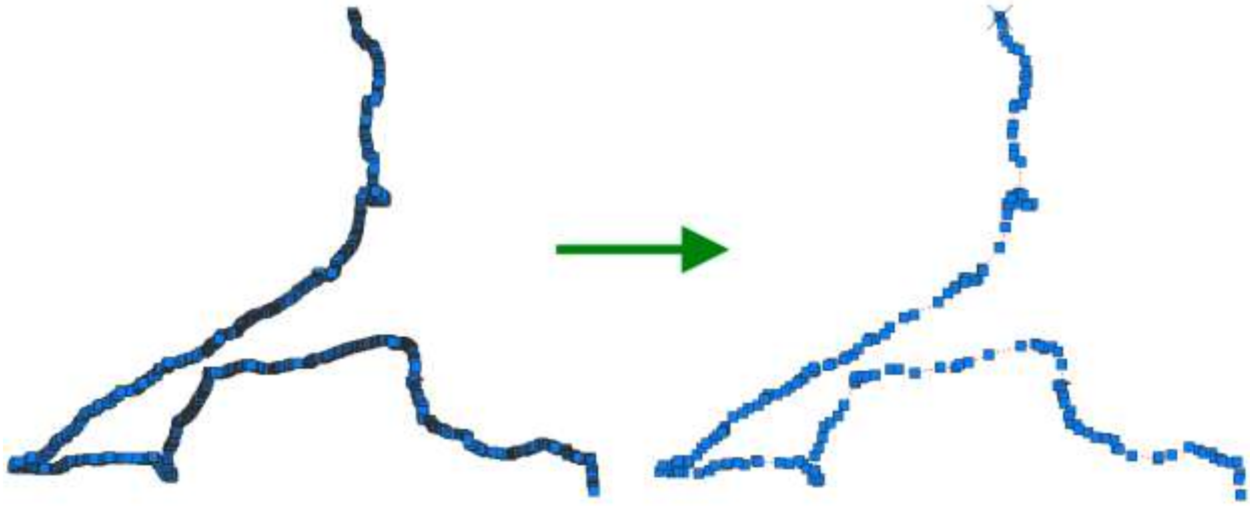


Figure 15: A polyline with 1682 vertices (left) reduced to a polyline with 182 vertices (right)

Command line prompt:

```
Number of vertices before    : 1682
Number of vertices after     : 182
Number of polylines processed: 1
Number of polylines failed   : 0
```

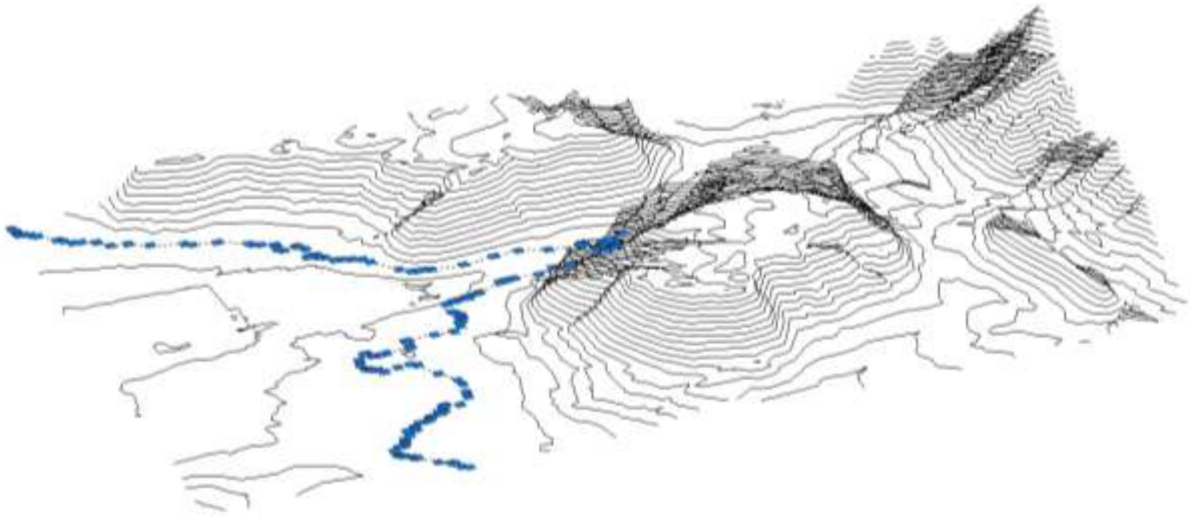


Figure 16: 37832 vertices in 307 polylines (one selected) reduced to 5851 vertices

Command line prompt:

```
Number of vertices before    : 37832
Number of vertices after     : 5851
Number of polylines processed: 307
Number of polylines failed   : 0
```

5.3 Slice lines

Slice 3d *line* entities.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Slice lines

Command entry: CC:LINES:SLICE

Dialog

`Select lines:`

Select the lines to slice.

`Specify origin point of plane:`

Specify the origin point of the slicing plane.

`Specify point on positive x-axis:`

Specify a point on the x-axis of the slicing plane.

`Specify third point on plane:`

Specify a third point on the slicing plane.

`Specify point on side to keep or [keep Both sides]:`

Specify a point on the side to keep or enter ‘B’ to keep both sides. Default is <B>

Summary

The command slices an arbitrary number of 3d *line* entities on a 3d slicing plane.

Example

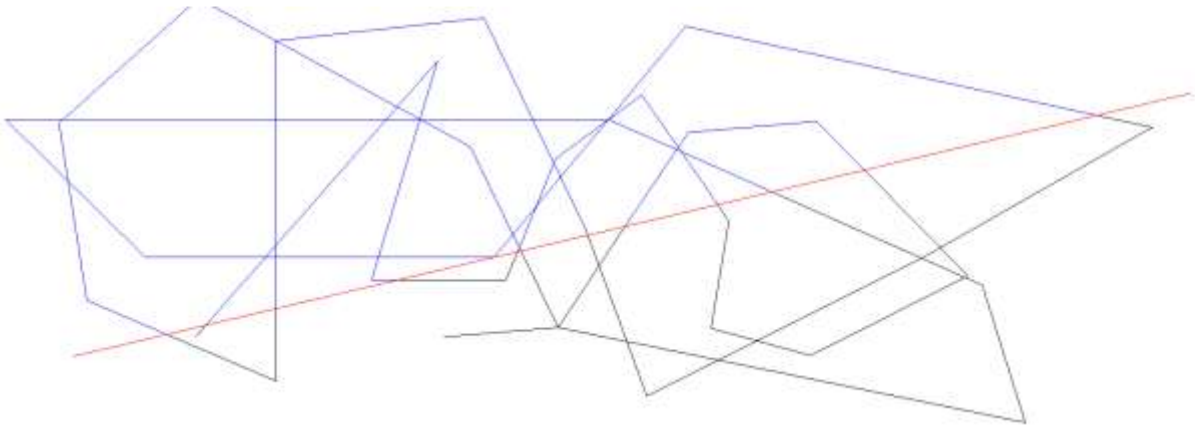


Figure 17: A couple of lines sliced along a vertical slicing plane (red)

5.4 Project lines onto a surface

Project lines onto a surface consisting of *3dface* entities.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Project lines

Command entry: CC:LINES:PROJECT

Dialog

`Select faces:`

Select the 3dfaces defining the surface

`Select lines:`

Select the lines to project.

`Specify projection direction [X/Y/Z/Ucs/2Points]:`

Select the projection direction.

<X>:	The lines are projected in global X-direction
<Y>:	The lines are projected in global Y-direction.
<Z>:	The lines are projected in global Z-direction. (default)
<Ucs>:	The lines are projected in UCS z-direction.
<2Points>:	The lines are projected in a user defined projection direction. The following dialog occurs:

> **`Specify first point`**
>
> Select the first point of the projection direction.
>
> **`Specify second point`**
>
> Select the second point of the projection direction.

`Insert on layer [Current/by Face/by Line]:`

Select the layer assignment for the projected lines.

<Current>:	The projected lines will be inserted on the current layer. The colour of each line will be the colour of its 3dface.
<by Face>:	The projected line will be inserted on the layer of the 3dface the line was projected onto. (default)
<by Line>:	The projected lines will be inserted on the layer of the original lines.

`Delete original lines [Yes/No]:`

Specify if the original lines shall be deleted.

<Yes>:	The original lines will be erased.
<No>:	The original lines will not be erased. (default)

Summary

The lines will be projected onto faces lying above and below the line in projection direction. For each line, start and end point are projected onto the surface. If a line crosses an edge of a face in projection direction, it will be split at the projected intersection point of edge and line. Consequently, there will be more projected lines than original lines in a general case.

The projection onto a specific face fails if the normal vector of the face is perpendicular to the projection vector or if the line to be projected runs parallel to the projection direction.

If the lines are inserted in the current layer, the colour of each line will be the colour of the face it is projected onto.

Example

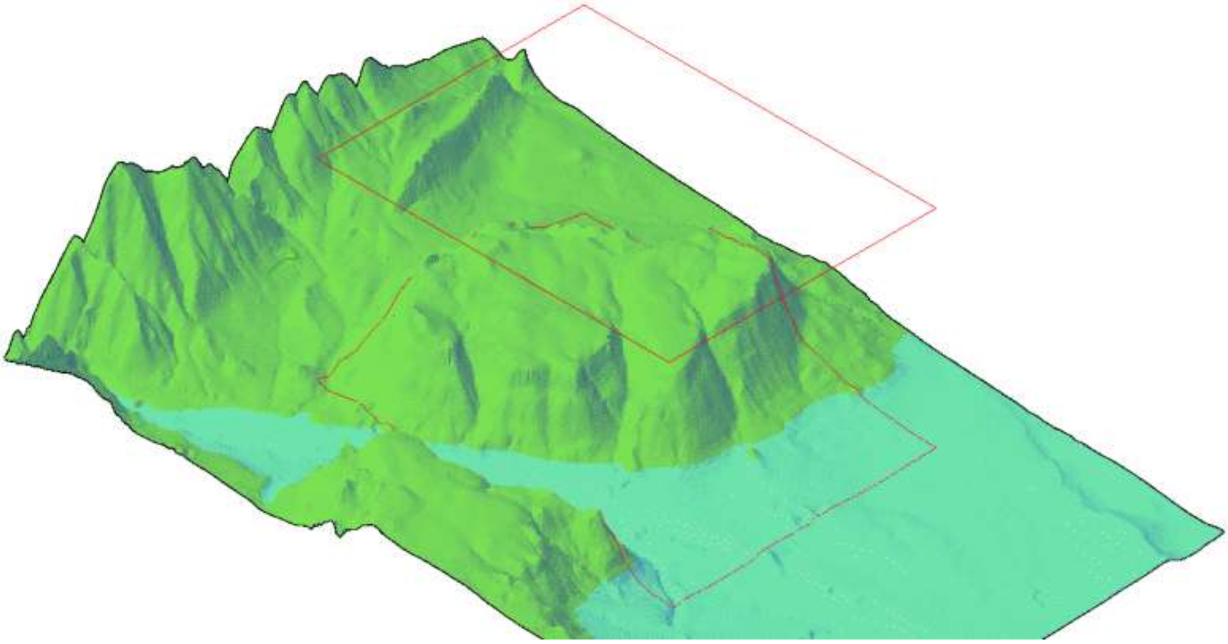


Figure 18: Four lines in the xy plane and their projection onto a surface

Command line prompt:

```
Number of lines projected            : 850
Number of failed faces               : 0
Faces parallel to projection direction: 0
Lines parallel to projection direction: 0
```

5.5 Develop a polyline

Compute the development (profile) in the xy plane of a 3d polyline.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Develop polyline

Command entry: CC:LINES:DEVELOP

Dialog

`Select polyline:`

Select a polyline, 2d polyline or 3d polyline consisting exclusively of line segments.

`Reverse polyline [Yes/No]:`

Specify if the development shall be computed for the reverse order of polyline vertices.

<Yes>: Compute the development for the reverse order of polyline vertices.

<No>: Compute the development for the normal order of polyline vertices. (default)

`Specify range [Yes/No]:`

Specify if you want to develop a specific arc length range of the polyline.

<No>: Compute the development for entire polyline. (default)

<Yes>: Compute the development for an arc length range of the polyline. The following dialog is displayed:

`Specify start arc length`

Specify the arc length of the polyline from where to start to compute the development. Default is 0.

`Specify end arc length`

Specify the arc length of the polyline where to stop to compute the development. Expects a positive double value. If greater than the maximum length of the polyline, the development will be computed until the maximum length of the polyline.

`Specify z-scaling <1>:`

Specify a scaling for the z-heights of the polyline. Expects a positive double value. Default is 1.

`Include first derivative (slope) [Yes/No]:`

Specify if the first derivative (profile slope) shall be drawn too.

<Yes>: The first derivative will be drawn together with the development.

<No>: The first derivative will not be drawn. (default)

`Specify outfile type [DWG/DXF]:`

Specify if the output file type.

<DWG>: The output file will be saved in the current dwg format.

<DXF>: The original lines will be saved in the current dxf format. (default)

Depending on the FILEDIA setting, either a file dialog is displayed or the outfile name must be entered directly.

Summary

The profile of a polyline is the development of the Z-height over the XY length of the polyline. The command draws the XY projection of the polyline on the X-axis and the Z-height of the polyline on the Y-axis. The development is saved either in AutoCAD dwg or dxf format.

Example

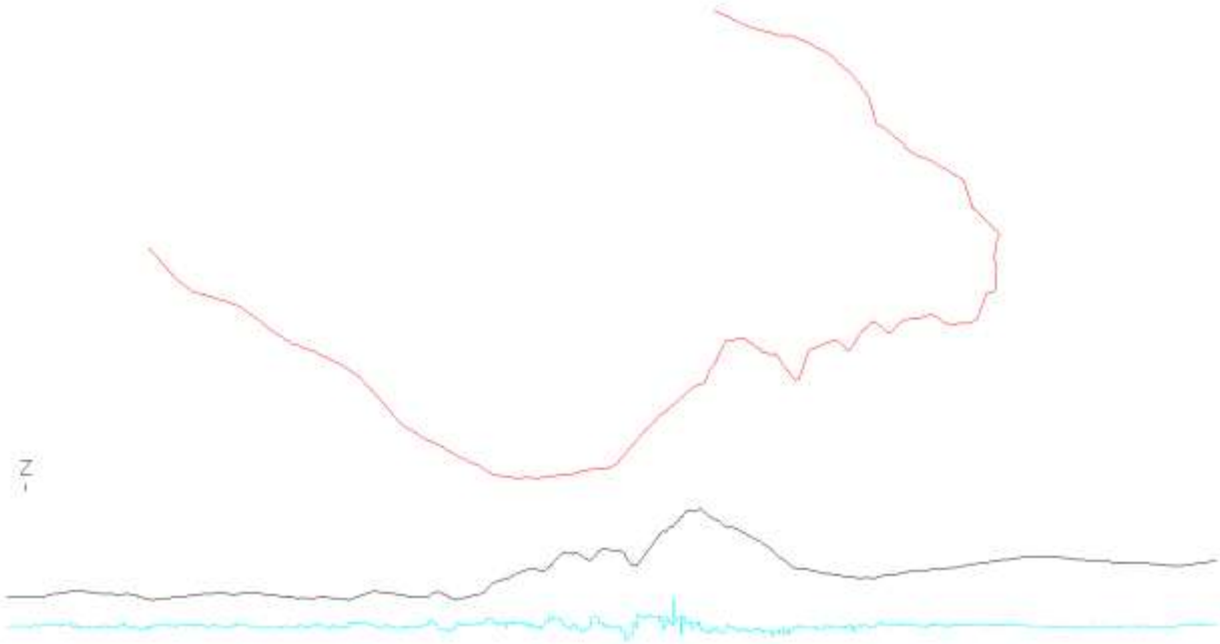


Figure 19: A 3d polyline (red), its development (black) and the first derivative of the development (cyan)

Command line prompt:

```
Number of vertices : 701.0000
Start arc length   : 0.0000
End arc length     : 9425.7085
Delta arc length   : 9425.7085
Start ground length: 0.0000
End ground length  : 8736.6754
Delta ground length: 8736.6754
Minimum slope [%]  : -201.0726
   at ground length: 4468.3306
Maximum slope [%]  : 383.3087
   at ground length: 4814.5793
Minimum elevation  : 5691.0948
Maximum elevation  : 6345.7523
Delta elevation    : 654.6575
```

6 Handling face primitives

ComputationalCAD for AutoCAD provides several methods to process *3dface* entities. Available methods allow to

- **compute contour lines** of a surface consisting of 3dface entities
- **slice a surface** consisting of 3dface entities

6.1 Compute contour lines

Compute contour lines of a surface consisting of *3dface* entities.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Compute contour lines

Command entry: CC:FACES:CONTOUR

Dialog

`Select faces:`

Select the 3dfaces defining the surface

`Specify reference plane [Wcs/Ucs/3Point]:`

Specify the plane to refer the elevation.

<Wcs>:	The elevation refers to the z-axis of the global coordinate system. (default)
<Ucs>:	The elevation refers to the z-axis of the UCS coordinate system.
<3Point>:	The elevation refers to the z-axis of a user defined coordinate system

`Specify start elevation:`

Enter the start elevation. The elevation refers to the z-axis of the reference plane specified above. Expects any numeric value. Default is <0>.

`Specify end elevation:`

Enter the start elevation. The elevation refers to the z-axis of the reference plane specified above. Expects any numeric value. Default is <0>.

`Specify spacing:`

Specify the spacing between two contour lines. The spacing refers to the z-axis of the reference plane specified above. Expects a positive, non-zero value. Default is <1>.

`Insert on layer [Current/by Face/by Elevation/by Index]:`

Specify on which layer the contour lines shall be inserted.

<Current>:	The contour lines will be inserted on the current layer.
<by Face>:	The contour lines will be inserted on the layer of the respective face.
<by Elevation>:	The contour lines will be inserted on a layer with the layer name containing the elevation of the contour line. The layer will be created it if it does not exist. (default) Following dialog is displayed:
<by Index>:	The contour lines will be inserted on a layer with the layer name containing the index of the contour line, starting from 1. The layer will be created it if it does not exist. Following dialog is displayed:

`Specify prefix string`

Specify the prefix of the layer name if <by Elevation> or <by Index> has been selected. Default is 'Contour_line_'.

Summary

The contour lines will be inserted as AutoCAD 3d polyline entities. Regardless of the selected layer insertion method, the color of a segment is always set to the color of the respective face. The contour lines are computed in planes parallel to the specified reference plane.

Example

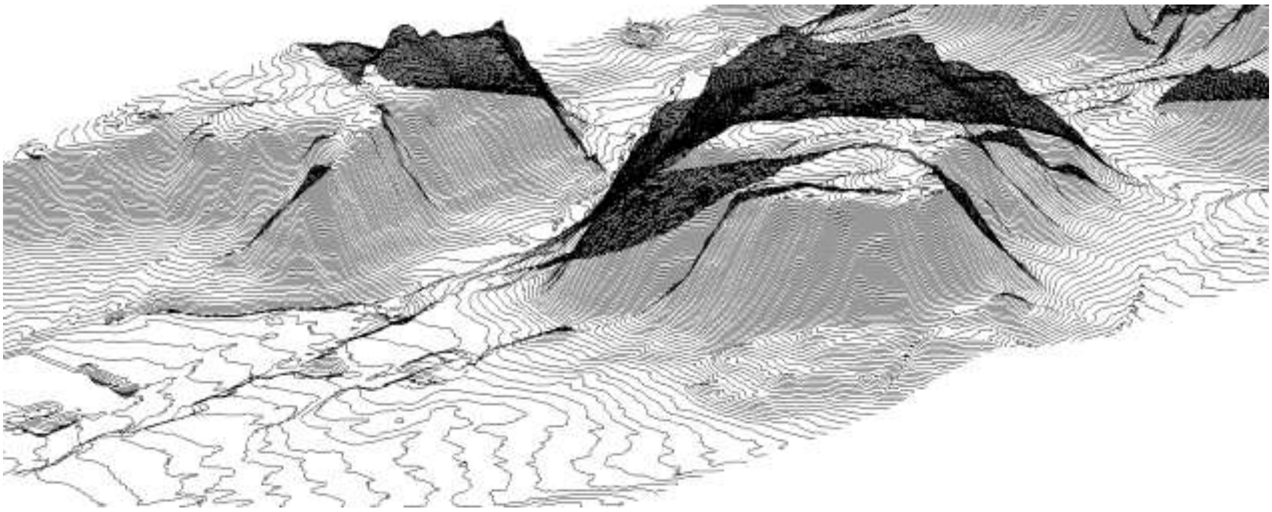


Figure 20: App. 180k contour lines in 2045 polylines computed from app. 107k faces.

Command line prompt:

```
Failed intersections     : 0
Degenerate intersections : 0
Total number of segments : 180439
Total number of polylines: 2045
```

6.2 Slice a surface

Slice a surface consisting of *3dface* entities.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Slice surface

Command entry: CC:FACES:SLICE

Dialog

`Select faces:`

Select the 3dfaces defining the surface.

`Specify origin point of plane:`

Select the origin point of the slicing plane.

`Specify point on positive x-axis:`

Select a point on the positive x-axis of the slicing plane.

`Specify third point on plane:`

Select a third point on the slicing plane.

`Specify point on side to keep or [keep Both sides]:`

Select a point on the side of the slicing plane to keep or 'B' to keep both sides. Default is <B>.

`Keep coplanar faces [Yes/No]:`

Select if faces coplanar to the slicing plane shall be kept. Default is <Yes>.

Summary

The command slices a surface consisting of AutoCAD *3dface* entities analogously to the AutoCAD slice solid command. Faces that intersect the slicing plane will be erased and replaced by two or three faces that respect the slicing plane. The orientation of the faces will be maintained.

Example

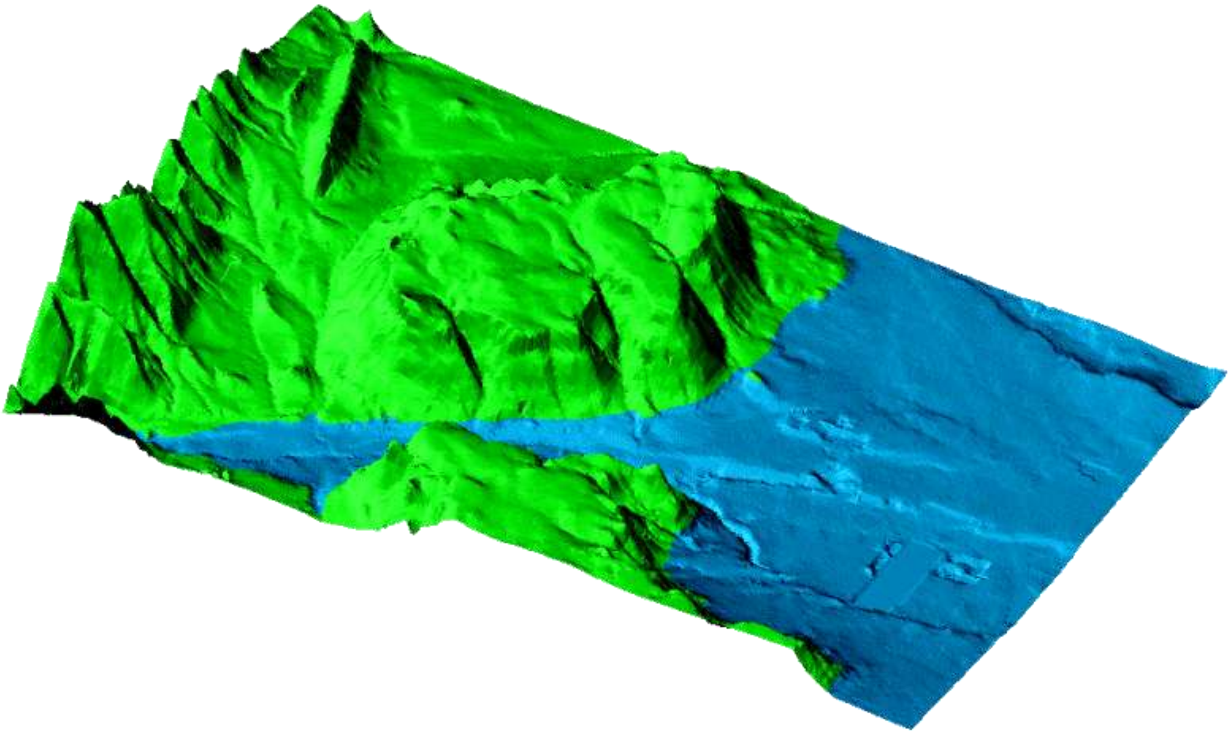


Figure 21: A sliced surface. Faces below slicing plane coloured blue, faces above slicing plane coloured green

Command line prompt:

```
Failed faces    : 0
Faces sliced    : 2170
Faces remaining: 109647
```

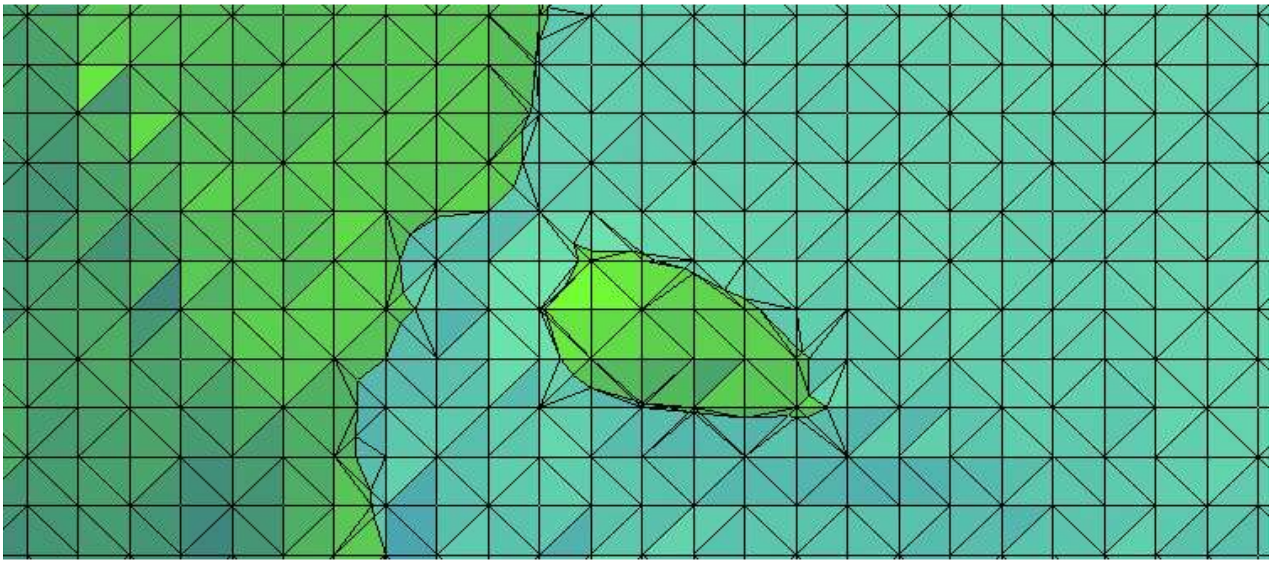
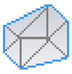


Figure 22: Sliced surface – detail (top view)

6.3 Convert unordered faces to mesh

Convert a surface consisting of unordered *3dface* entities into a 3d mesh. **This method is only available for AutoCAD versions 2010 or higher.**

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Convert faces to mesh

Command entry: CC:FACES:TOMESH

Dialog

`Select faces:`

Select the 3dfaces defining the surface.

`Delete original faces [Yes/No]:`

Select if the original faces shall be deleted. Default is <Yes>.

Summary

A mesh is an advanced data structure that has several advantages over unordered faces:

1. The **visualization performance** for a mesh is several magnitudes better than for unordered faces. A mesh easily allows orbiting millions of faces with full shading in real time.

2. **Bitmap textures** can be applied on a mesh in a whole allowing to produce **high quality renderings** e.g. of landscapes.

3. A mesh can be **smoothed**.

4. A mesh is stored with app. **25% less disk space** than unordered triangular faces.

A mesh can simply be exploded into its underlying faces again. The command combines unordered AutoCAD 3d faces with identical layer and color properties to an AutoCAD mesh. Consequently, the command creates as much meshes as there are faces with different layer and color properties.

Example

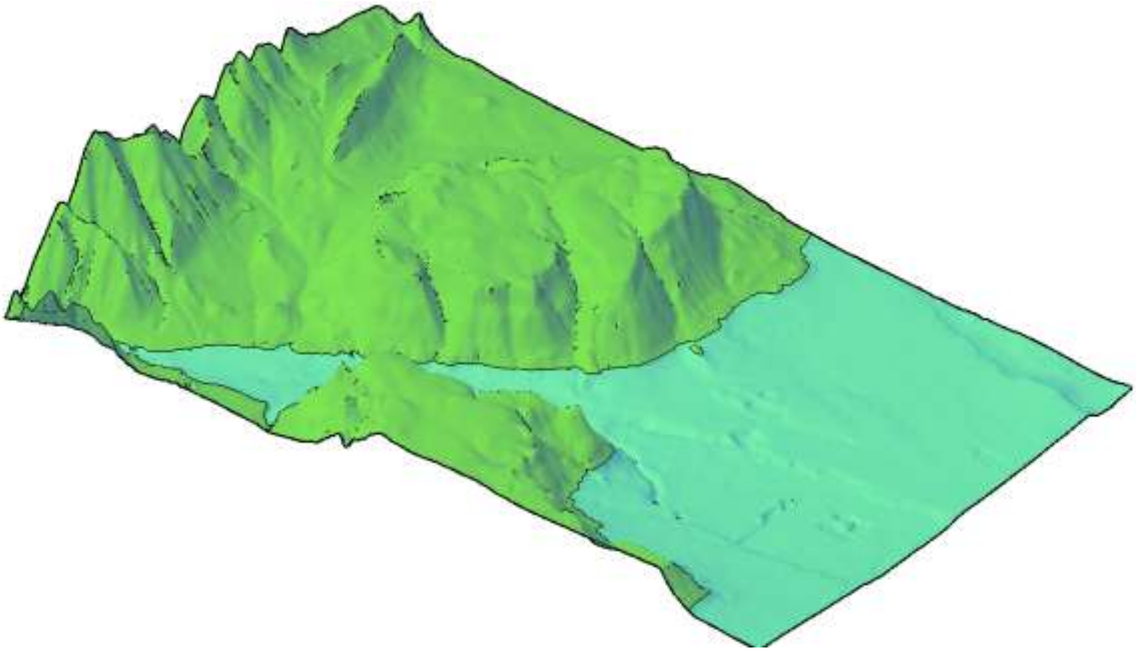


Figure 23: Two meshes generated from 107k faces

Command line prompt:

```
Mesh    0:
 Layer name         : water
 Number of vertices: 23605
 Number of faces    : 45457
Mesh    1:
 Layer name         : ground
 Number of vertices: 32139
 Number of faces    : 62255
```

6.4 Convert unordered faces to solid

Convert a surface consisting of unordered *3dface* entities into a 3d solid by extrusion.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Convert faces to solid

Command entry: CC:FACES:TOSOLID

Dialog

`Select faces:`

Select the 3dfaces defining the surface.

`Specify reference plane [Wcs/Ucs/3Point]:`

Specify the extrusion reference plane. Default is <Wcs>.

`Extrusion height in actual Z:`

Specify the extrusion height with respect to the global z-axis. Default is <-1>.

`Minimum projected edge length:`

Specify the minimum length of the projection of the faces onto the reference plane. Default is <0.01>.

`Union solids [Yes/No]:`

Select if the extruded solids shall be united. Default is <Yes>.

Summary

This method extrudes each face in z-direction and unites the resulting solids. In order to do this, the projection of the input faces onto the reference plane must not be degenerate. In order to achieve this, the projected faces will be healed so that no projected edge will be shorter than specified.

Converting faces to solids allows for numerous advanced operations, including **Boolean operations** and **mass property computation**. While extrusion is computationally not costive, AutoCAD solids are not optimized for Boolean union operation performance of tens or hundreds of thousands of sub-entities. Thus, being theoretically unbound in the number of input faces, this method does practically not support extremely large input with the unite solids option. 5000 to 10000 faces may be united in about a minute.

Example

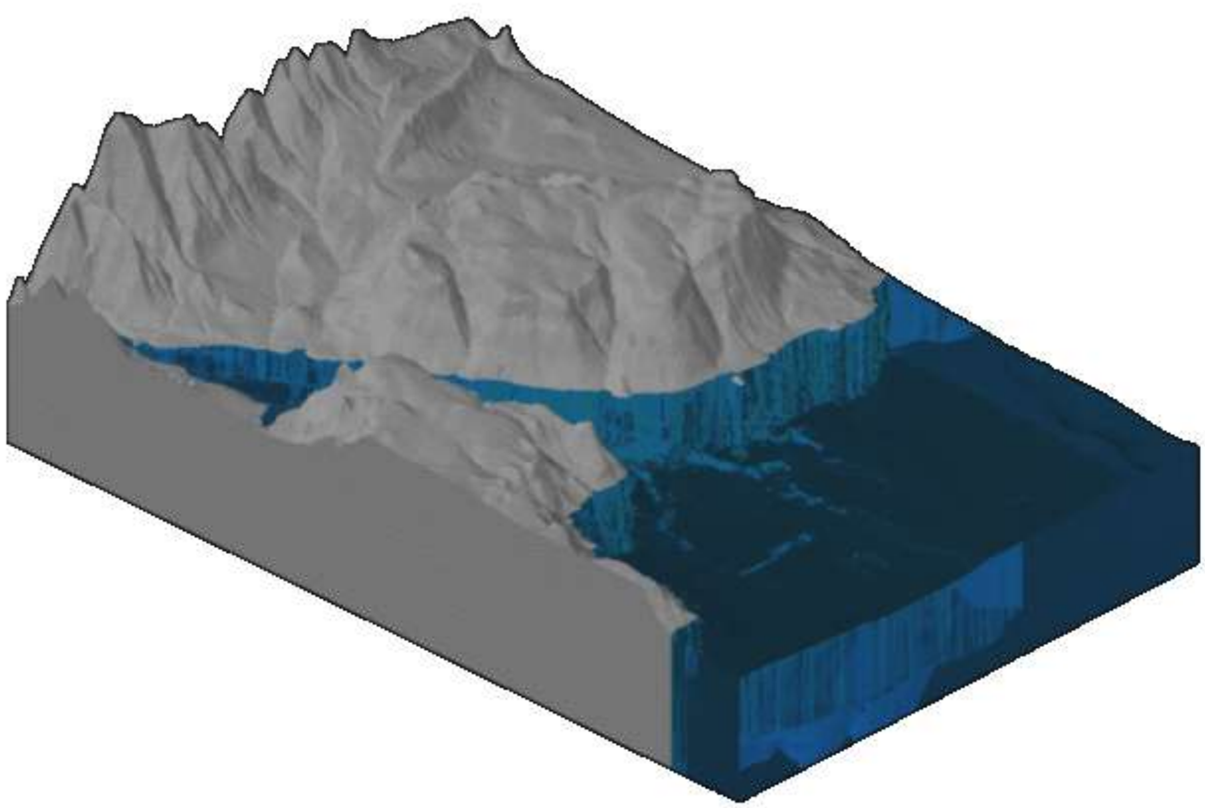


Figure 24: Rendered view on two solids build from 107k faces

6.5 Compute silhouette of unordered faces

Compute the silhouette region of a surface consisting of unordered *3dface* entities on a reference plane.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Compute silhouette

Command entry: CC:FACES:SILHOUETTE

Dialog

`Select faces:`

Select the 3dfaces defining the surface.

`Specify reference plane [Wcs/Ucs/3Point]:`

Specify the reference plane of the silhouette. Default is <Wcs>.

`Minimum projected edge length:`

Specify the minimum length of the projection of the faces onto the reference plane. Default is <0.01>.

Summary

The silhouette of a surface is the visible outer bound of all faces. In order to do this, the projection of the input faces onto the reference plane must not be degenerate. In order to achieve this, the projected faces will be healed so that no projected edge will be shorter than specified.

Example

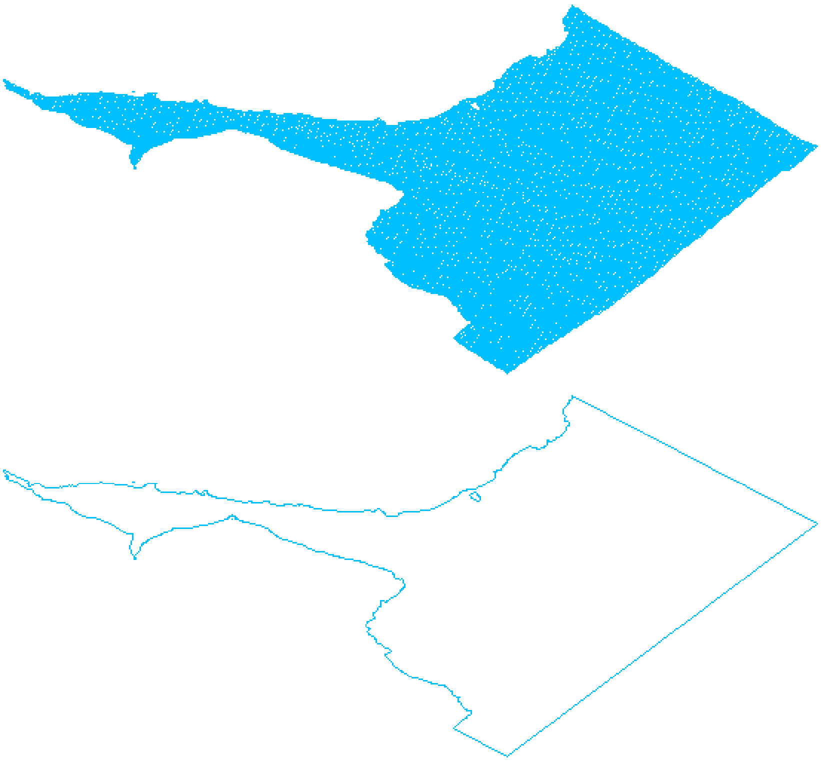
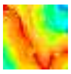


Figure 25: 45k faces and silhouette region thereof (below)

6.6 Colorize face properties

Colorize various properties of a surface consisting of 3d faces.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Colorize faces

Command entry: CC:FACES:COLORIZE

Dialog

`Select faces:`

Select the 3dfaces defining the surface.

`Specify target property [ARea/Center Z/minimum ANgle/MINimumZ/MAXimumZ] <ARea>:`

Specify the property to colorize. Default is <ARea>.

`Specify number of colors <6>:`

Specify the number of colors to use Expects an integer between 2 and 32768. Default is <6>.

`Specify lower cutoff percentage <0>:`

Specify the the lower cutoff percentage. Default is <0>.

`Specify upper cutoff percentage <100>:`

Specify the the upper cutoff percentage. Default is <100>.

Note

The faces will be colorized in the order blue – cyan – green – yellow – red – magenta where the blue color value is assigned to the face(s) with the smallest selected target property value and the magenta color value is assigned to the face(s) with the highest selected target property value. The cutoff percentages allow specifying the color of the minimum and maximum target property values as shown in the first example.

The center Z, minimum Z and maximum Z target properties are best applicable to a terrain surface.

The minimum Angle property allows visualizing the triangulation quality.

The area property visualizes areas with high “density” of the faces defining a surface (densit plot).

Example

In below figure, following color schemes have been applied:

a) 6 colors, from 0% to 100%
b) 6 colors, from 0% to 100%, colors reversed
c) 100 colors, from 0% to 100%
d) 100 colors, from 20% to 80% (i.e. all values smaller than 20% of the value range are colored blue and all values greater than 80% of the value range are colored magenta)
e) 100 colors, from -20% to 140%. Specifying negative values for the lower cutoff value and values greater than 100% for the upper cutoff value, respectively, influences the colors for the minimum and maximum target property, respectively.

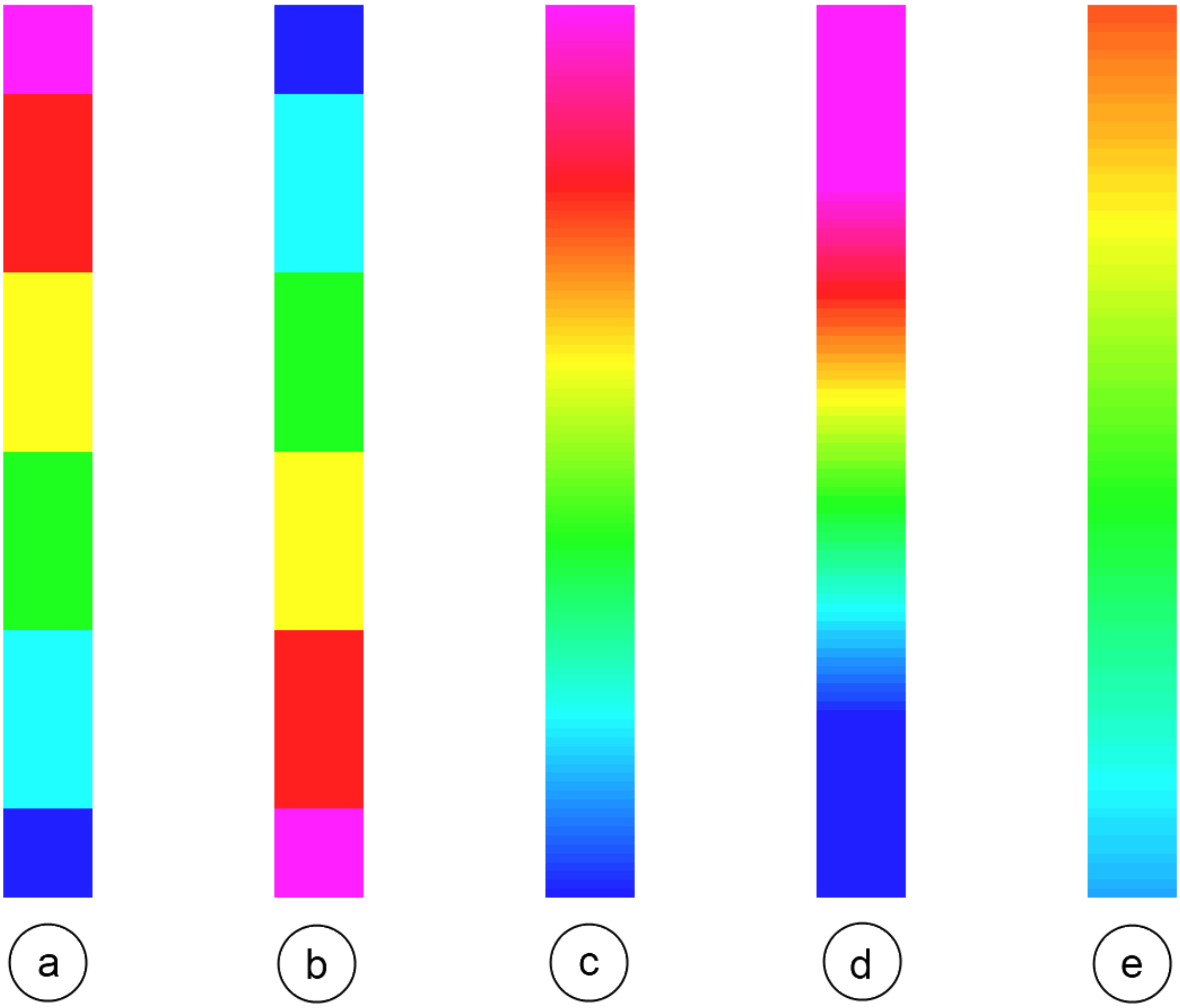


Figure 26: Sample color schemes

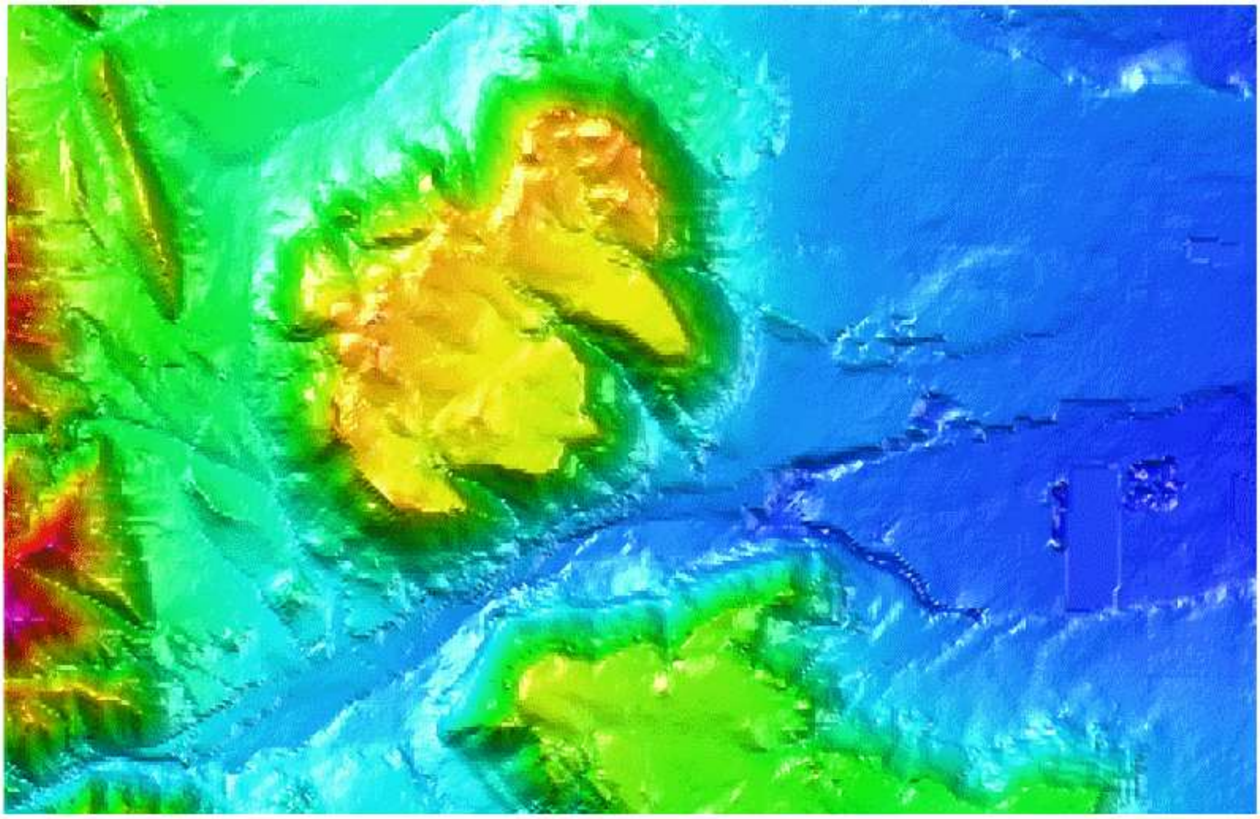


Figure 27: Top view on a terrain with colored minimum z-height property.

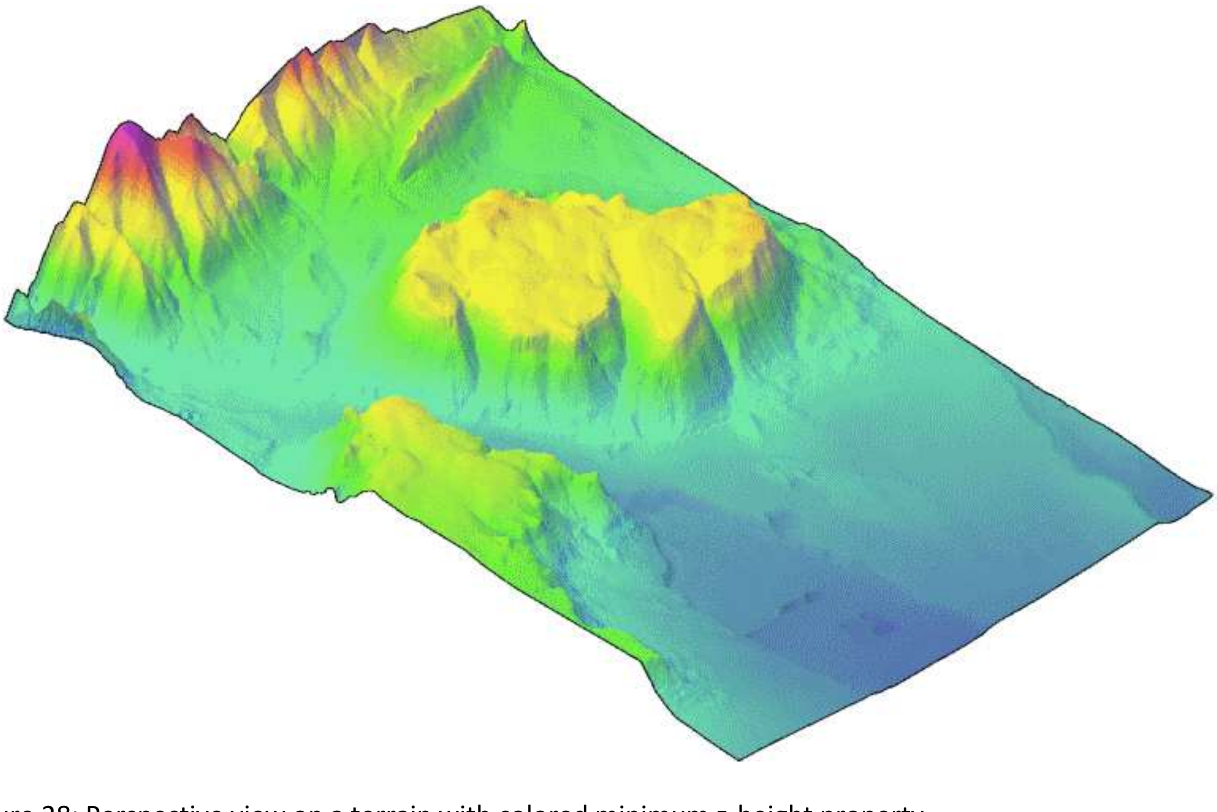


Figure 28: Perspective view on a terrain with colored minimum z-height property.

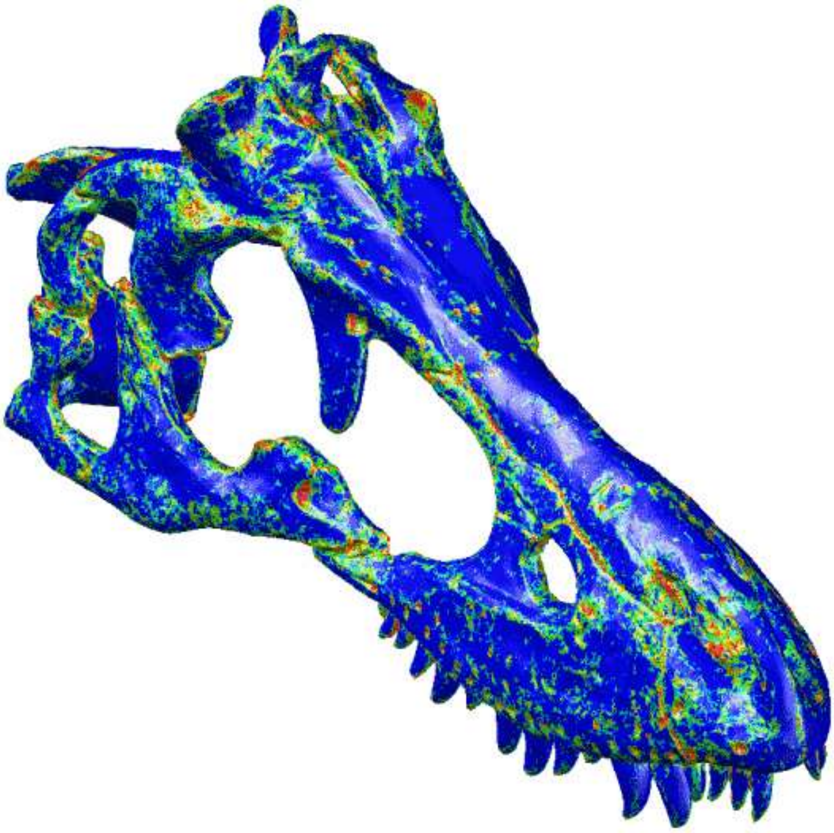


Figure 29: Dinosaur skull scan with colored area property (face density plot).

7 Delaunay Triangulations

Conforming Delaunay triangulations (CDTs) are a key requirement for quality Digital Terrain Modeling (DTM). In addition to just triangulating point data, a CDT allows to respect constraints and boundaries: edges and arbitrary shaped convex or concave holes, islands and outer bounds can become part of the triangulated surface while maintaining the Delaunay property.

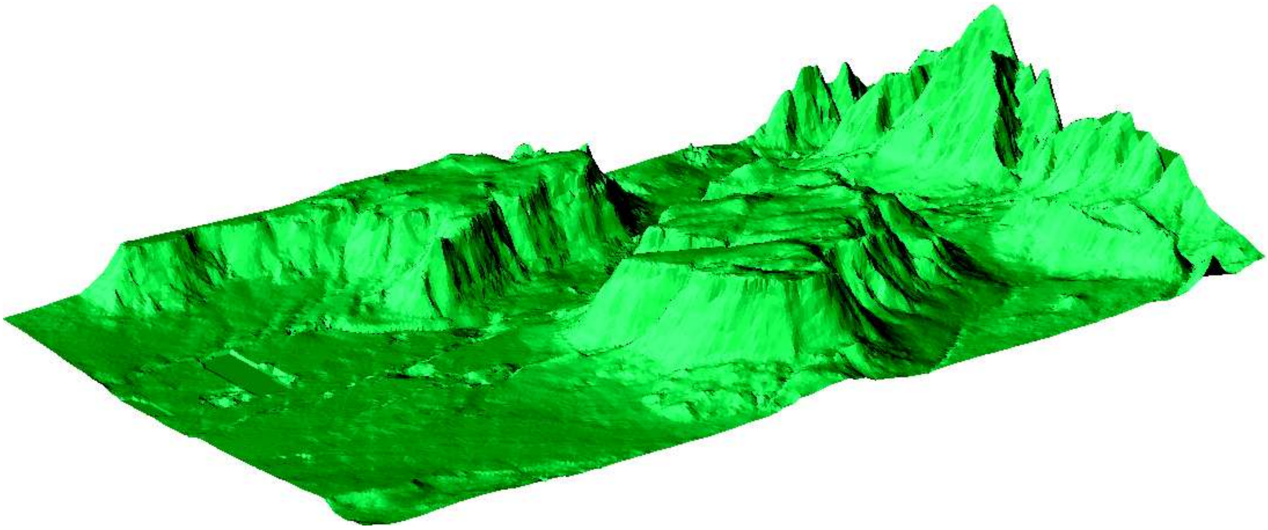


Figure 30: A Delaunay triangulated surface comprising app. 107k faces

ComputationalCAD for AutoCAD provides a Delaunay triangulation algorithm eligible for large scale Digital Terrain Modelling (DTM). *ComputationalCAD* for AutoCAD allows to

- **triangulate point data**
- **make lines part of the triangulation**
- **consider holes and islands**
- **reduce the number of vertices of an existing triangulation**
- **generate contour lines of a triangulation**

7.1 Theory

A 2d **Delaunay triangulation** (DT) for a set P of points in the plane is a triangulation such that no point in P is inside the circumcircle of any triangle in the triangulation. It can be shown that for all possible triangulations of P, a Delaunay triangulation maximizes the minimum angle of all angles of the triangles in the triangulation.

Thus, a Delaunay triangulation tends to avoid “skinny” triangles. This property makes it the triangulation of choice for many purposes, including Digital Terrain Modelling (DTM).

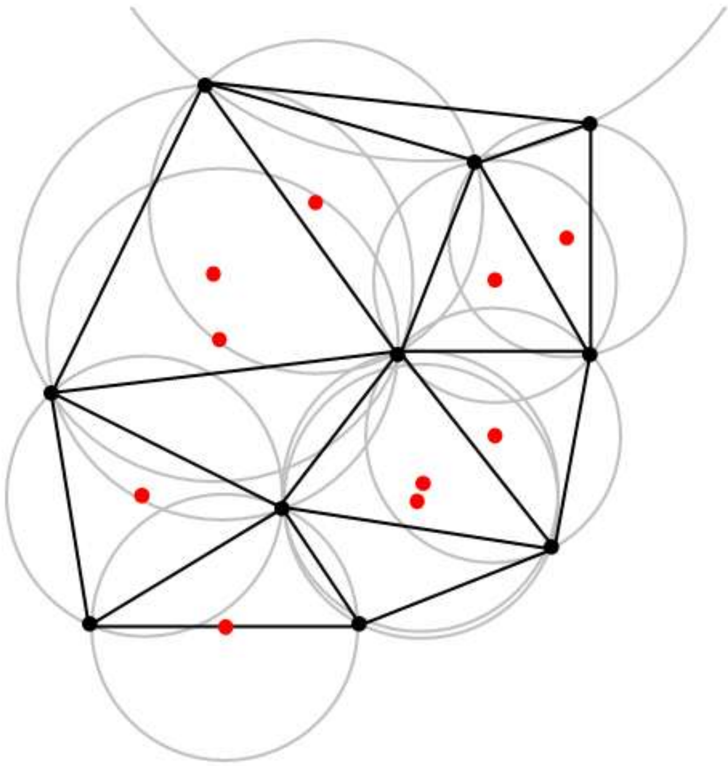


Figure 31: A Delaunay triangulation with all circumcircles and their centres. Image available under GNU license at http://en.wikipedia.org/wiki/File:Delaunay_circumcircles_centers.png

A Delaunay triangulation is unique in a general case. It is not unique if four triangulation points lie on the same circle.

A 2d **conforming Delaunay triangulation** (CDT) is a Delaunay triangulation that respects constraints (edges). This is done by iteratively inserting additional points (called Steiner points) until no triangle crosses a constraint.

Computational power

In general, triangulating pure point data is much faster than triangulation pure constraint data. This is because constraints are processed iteratively until no constraint crosses a triangle. Benchmarks for pure

constraint data cannot be given because the number of iterations depends on the distribution of the constraints.

On an average 32bit machine, *ComputationalCAD* for AutoCAD triangulates about 0.5M to 1M points in about one minute. This may extend to several millions of points on a 64bit machine. The computational complexity is $O(n \cdot \log(n))$, resulting in near-linear computation time over the number of triangulation points. However, the maximum number of triangulation points is limited by the available amount of memory.

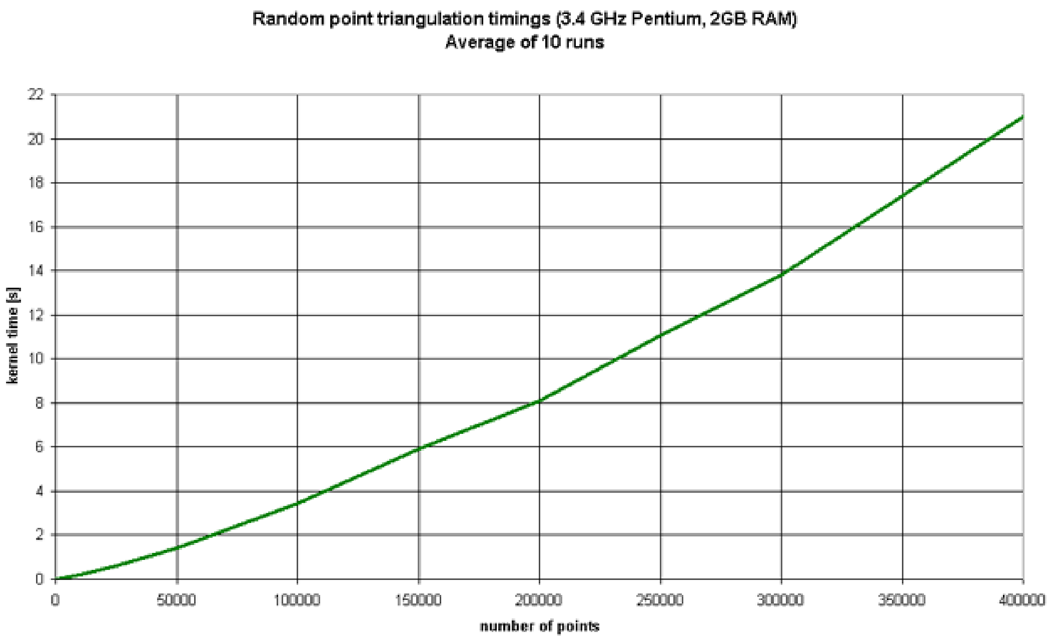


Figure 32: Triangulation timings

7.2 Input data

ComputationalCAD for AutoCAD can process the following input data:

- **Triangulation points** are defined as arbitrarily spaced AutoCAD 3d point entities. All triangulation points will be vertices of the triangles in the CDT.

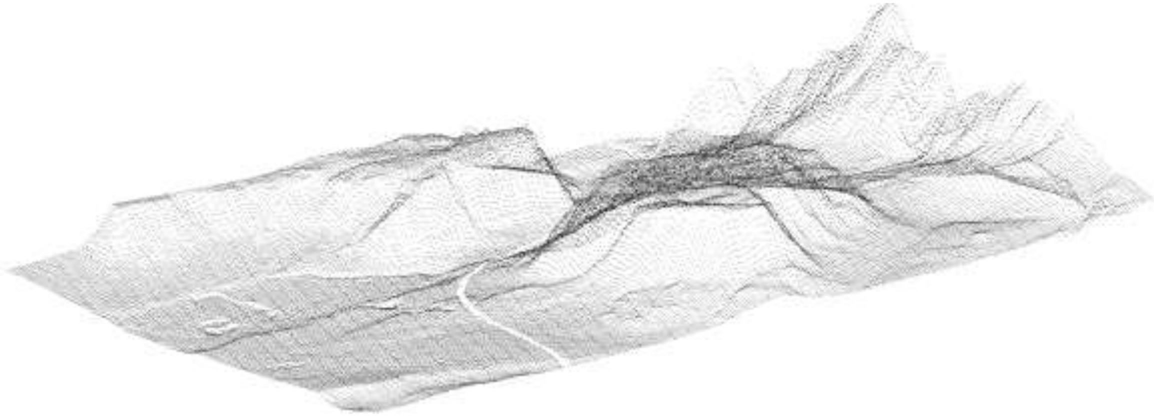


Figure 33: 54k triangulation points

- **Constraints** are defined as an unordered set of non self-intersecting, non-overlapping AutoCAD 3d line entities. The CDT will insert additional points so that no constraint will cross an edge of a triangle. Thus, spatial constraints become part of the triangulated surface.

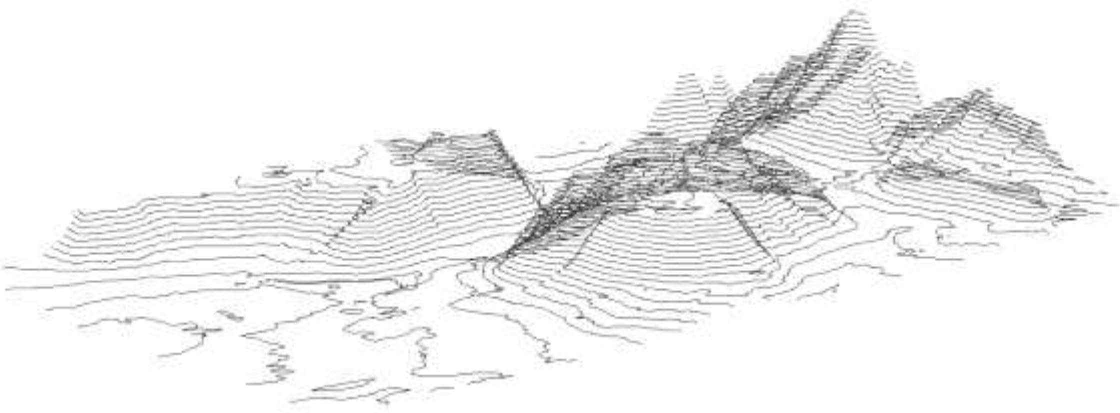


Figure 34: 35k contour lines (constraints)

- **Boundaries** are defined as a set of closed, linear AutoCAD polyline entities. Boundary regions may overlap. Boundaries are not exactly part of the triangulation but will be projected on the triangulated surface after the triangulation process. The CDT will insert additional points so that no projected boundary will cross an edge of a triangle. Boundaries allow defining arbitrary shaped convex or concave holes, islands and outer bounds of the triangulated surface.

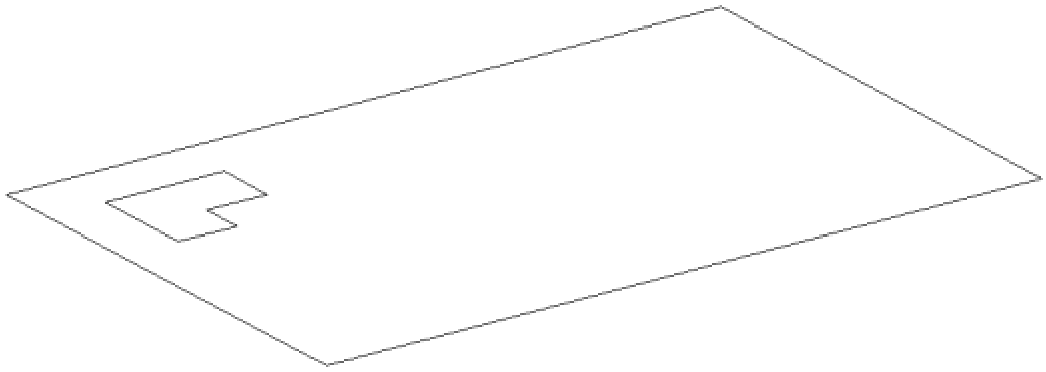


Figure 35: Two closed linear polylines forming two boundary regions

7.3 Restrictions

There are following general restrictions:

- **The triangulation points and constraints must be projectable**: a 2d CDT can intrinsically not triangulate points with identical xy-coordinates or recessing caves. Therefore, triangulation points with identical xy-coordinates will be removed during the triangulation process. The point with the highest z-coordinate is kept.

  General rule: the CDT can only "see" the xy-projection of the triangulation points and constraints in UCS. It has no height information during the triangulation process.

  Use the CC:POINTS:ELIM2D command to eliminate points with identical xy-coordinates before triangulating. This keeps your input data clean.

- **Constraints must not overlap and must not be self-intersecting**. Constraints may have identical start or end points and may be collinear. However, they must not overlap, be self-intersecting or coincident: since the CDT operates in the UCS xy-plane only, degenerate constraints define over-determined points along their intersection (i.e. possibly different z-heights at the same xy-coordinate).

  Use the AutoCAD command _overkill to eliminate overlapping or coincident lines.

- **Boundaries must be closed and linear**. The CDT only accepts closed linear polyline objects as boundaries. The polylines must exclusively consist of line segments.

  Use the AutoCAD command _decurve to linearize a polyline if it does not exclusively consist of line segments.

- **Boundaries must lie inside the convex hull of triangulation points and constraints**. Boundaries allow defining arbitrary shaped convex and concave shaped holes, islands and bounds in the triangulated surface. This implies that boundaries can only be defined where a triangulated surface exists, precisely being the area inside the convex hull of triangulation points and constraints.

- **A Delaunay triangulation is not unique over an evenly spaced rectangular raster.** As a consequence, the direction of the diagonal in a raster may alter when triangulating identical point data twice depending on the insertion order of the triangulation points.

Figure 36: Two valid Delaunay triangulations over a rectangular raster

7.4 CDT command

Perform a 2d conforming Delaunay triangulation on a selection of triangulation points, constraints and boundaries.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Triangulate

Command entry: CC:CDT

Dialog

`Select triangulation points:`

Select the triangulation points. This is optional if constraints will be selected. Expects a selection of AutoCAD 3d *point* entities.

`Select constraints:`

Select the constraints. Optional if triangulation points have been selected. Expects a selection of non-overlapping AutoCAD 3d *line* entities. If lines have been selected, the following dialog occurs:

> **`Number of feasible constraint violations:`**
>
> Specify the number of feasible edge violations to stop the edge insertion iteration. Expects an integer greater or equal 0. Default is 0.

`Select boundaries:`

Select the boundaries (optional). Expects a selection of closed AutoCAD 2d polyline entities.

[The triangulation starts.]

`Insert on layer [Current/specify Name] :`

<Current>: The triangles will lie on the current layer. (Default)

<specify Name>: The following dialog is displayed:

> **`Specify layer name:`**
>
> Enter the name of the layer the triangles shall be added to. If the layer does not exist, it will be generated.

`Insert as block? <Yes, No> :`

<Yes>: The following dialog is displayed:

> **`Specify block name:`**
>
> Enter the name of the block the triangles shall be added to. If the block does not exist, it will be generated.

<No>: The triangles will be inserted in the model space. (Default)

Notes

Please read the comments on the input data and the general restrictions.

Example

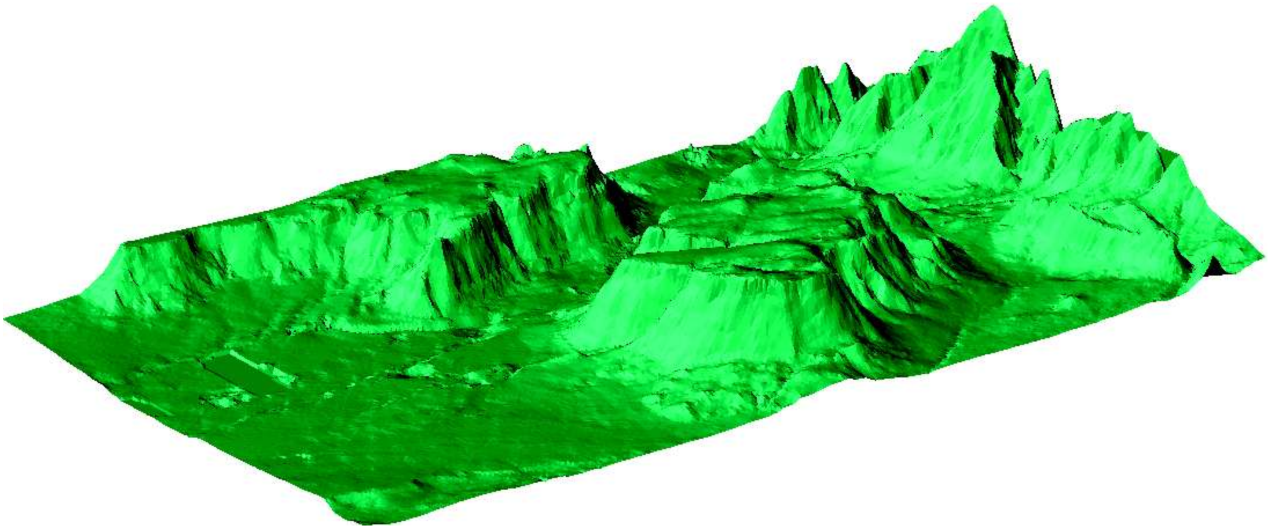


Figure 37: Rendered view on a pure point data Delaunay triangulation of app. 54k points

Command line prompt:

```
Initial triangulation:
----------------------
Initial triangulation points  : 54327
Initial constraints           : 0
Number of boundary regions    : 0
Initial boundary segments     : 0

Triangulation results
---------------------
Invalid triangulation points  : 0
Invalid constraints/boundaries: 0
Degenerate triangles          : 0
Steiner points added          : 0
Iterations for conformity     : 0
Total triangulation points    : 54327
Total triangles created       : 107712
Total time elapsed            : 2234 ms
```

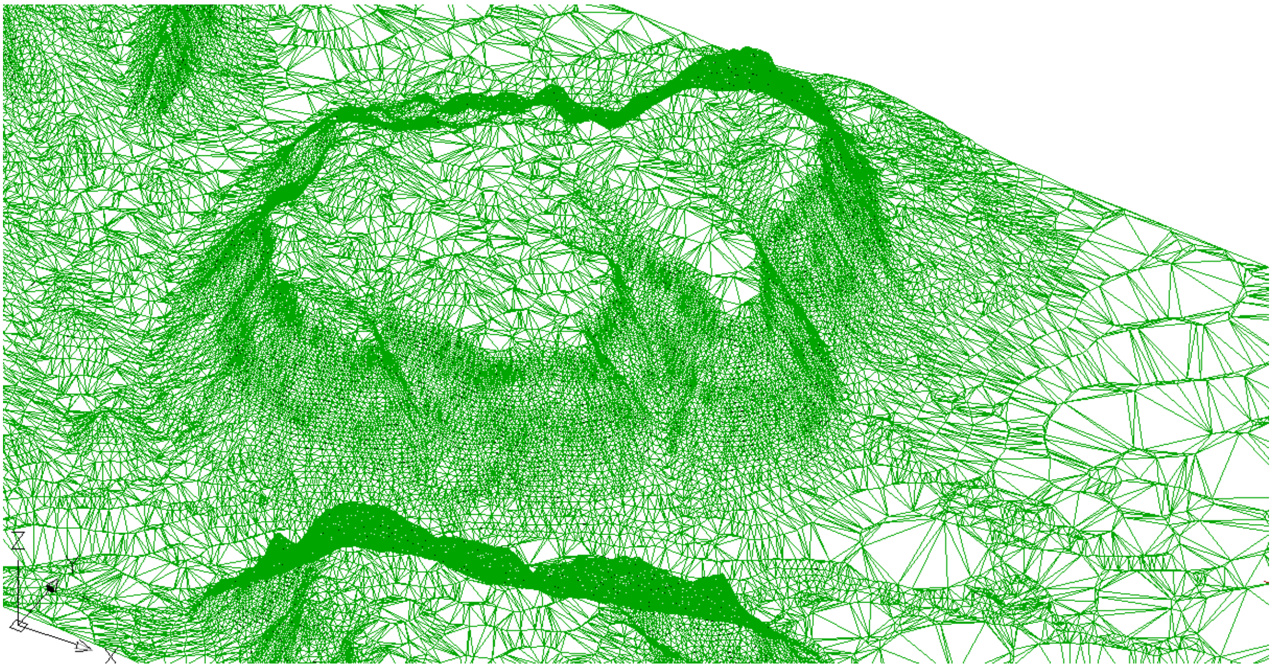


Figure 38: Wireframe view on a pure constraint Delaunay triangulation of app. 45k contour line constraints

Command line prompt:

```
Initial triangulation:
----------------------
Initial triangulation points  : 0
Initial constraints           : 45347
Number of boundary regions    : 0
Initial boundary segments     : 0

Triangulation results
---------------------
Invalid triangulation points  : 45073
Invalid constraints/boundaries: 2
Degenerate triangles          : 0
Steiner points added          : 17900
Iterations for conformity     : 13
Total triangulation points    : 63521
Total triangles created       : 126523
Total time elapsed            : 12460 ms
```

8 Surface reconstruction

ComputationalCAD for AutoCAD allows reconstructing a surface consisting of 3d faces from a wireframe model consisting of millions of unordered lines.

8.1 Reconstruct surface from wireframe command

Reconstruct a surface consisting of triangular and quad 3d faces from a wireframe consisting of unordered lines.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Reconstruct faces from wireframe

Command entry: CC:LINES:TOFACES

Dialog

`Select lines:`

Select the lines

`Insert on layer [Current/by Line]:`

<Current>:	The faces will lie on the current layer.
<by Line>:	The faces will lie on the layer of the defining lines. (default)

`Specify output entity type [All/Triangles only/Quads only]:`

<All>:	Both triangular and quad faces will be reconstructed (default).
<Triangles only>:	Only triangular faces will be reconstructed.
<Quads only>:	Only quad faces will be reconstructed.

`Specify number of relevant decimal digits <6>:`

Specify the number of relevant decimal digits of the coordinates of the start and end point of the lines. Expects an integer between 0 and 12. Default is 6.

Summary

This method identifies all triples and quadruples of connected lines that form a closed triangular or quad face (“wireframe”). The lines may be completely unordered. The direction of the line may be arbitrary. It then creates a triangular or quadrilateral AutoCAd 3d face for each identified tuple.

If the insertion layer is ‘byLine’, subsets of lines with the identical layer and colour are built before reconstructing the surface. Surfaces are then reconstructed for each subset one after another.

The output entity type allows specifying if only triangular, quadrilateral or all identified tuples shall be considered.

Before reconstructing the surface, the vertex coordinates will be internally rounded to the number of relevant decimal digits specified.

Example

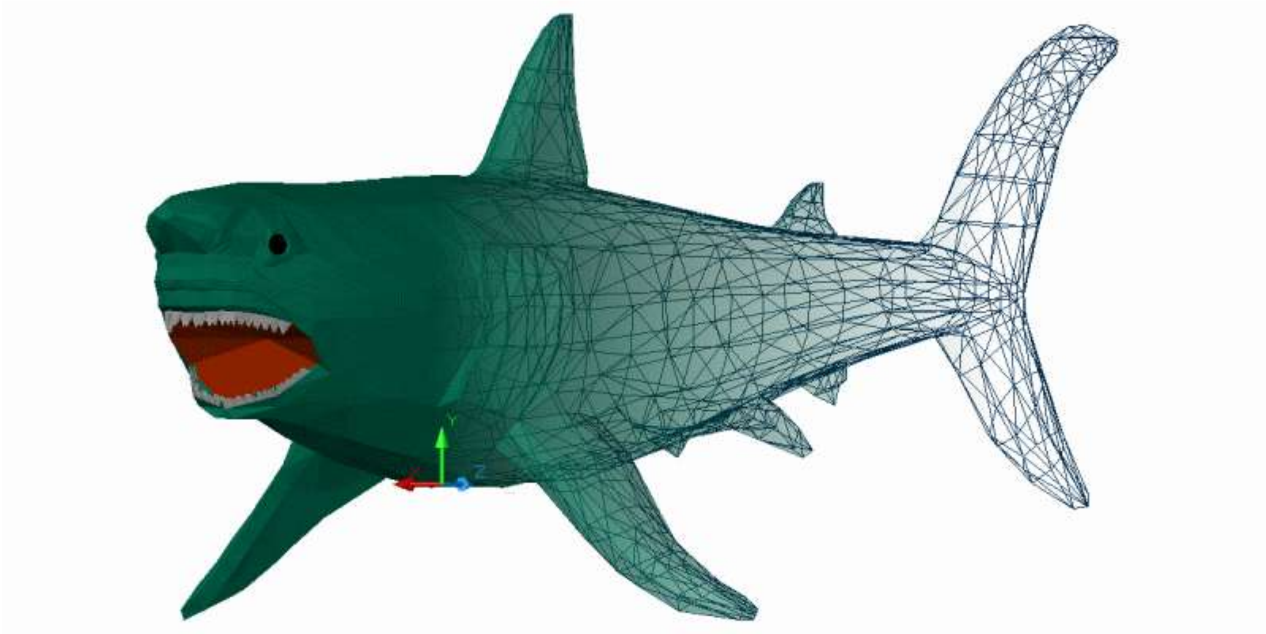


Figure 39: Surface consisting of 3d faces reconstructed from unordered lines

9 Convex Hulls and bounding entities

ComputationalCAD for AutoCAD provides several methods to compute 2d and 3d convex hulls of point clouds. Related to this, it also provides methods to compute minimum enclosing bounding rectangles, circles and boxes of the convex hulls. This is identical to computing the minimum enclosing bounding rectangles, circles and boxes of the entire point cloud.

9.1 2d convex hull

Compute the 2d convex hull of a point cloud in the plane.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ 2d convex hull

Command entry: CC:HULL:2D

Dialog

`Select points:`

Select the points for which to compute the 2d convex hull.

`Specify projection direction [X/Y/Z/Ucs/2Points]:`

Select the projection direction.

<X>:	The hull is computed in the global YZ-plane
<Y>:	The hull is computed in the global XZ-plane.
<Z>:	The hull is computed in the global XY-plane (default).
<Ucs>:	The hull is computed in the UCS XY-plane.
<2Points>:	The hull is computed in a user defined plane perpendicular to the projection direction. The following dialog occurs:

`Specify first point`

Select the first point of the normal vector defining the plane.

`Specify second point`

Select the second point of the normal vector defining the plane.

Notes

The 2d convex hull is the planar convex polygon that encloses all points with minimum perimeter length. If the points are 3d points, the 2d convex hull is computed for the projection of these points onto the specified projection plane.

Use Generate points on primitives and Generate points on solids to generate input data.

Example

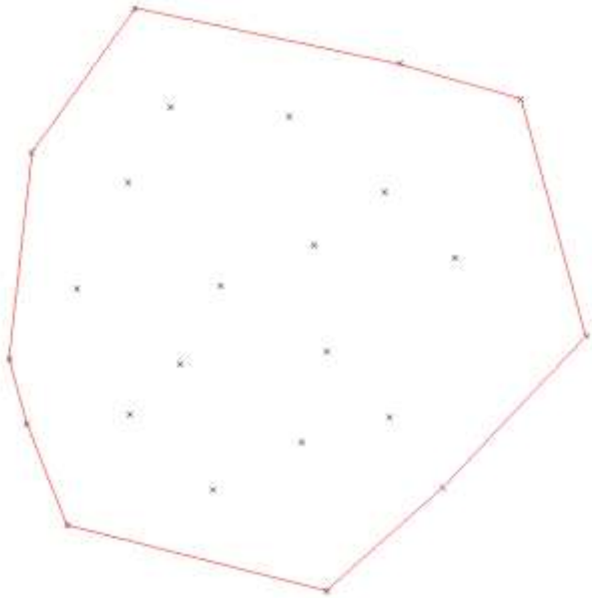


Figure 40: A 2d convex hull of 24 points

Command line prompt:

```
Number of vertices on hull : 10
Hull perimeter length      : 2156.6425
Enclosed area in hull plane: 337976.7258
```

9.2 Minimum area enclosing rectangle

Compute the minimum area enclosing rectangle of a point cloud in the plane.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Min. enclosing rectangle

Command entry: CC:HULL:MINAREA

Dialog

`Select points:`

Select the points for which to compute the minimum area enclosing rectangle.

`Specify projection direction [X/Y/Z/Ucs/2Points]:`

Select the projection direction.

<X>:	The rectangle is computed in the global YZ-plane
<Y>:	The rectangle is computed in the global XZ-plane.
<Z>:	The rectangle is computed in the global XY-plane. (default)
<Ucs>:	The rectangle is computed in the UCS XY-plane.
<2Points>:	The rectangle is computed in a user defined plane perpendicular to the projection direction. The following dialog occurs:

`Specify first point`

Select the first point of the normal vector defining the plane.

`Specify second point`

Select the second point of the normal vector defining the plane.

Notes

The 2d minimum area enclosing rectangle is the rectangle that encloses all points with minimum area. If the points are 3d points, the 2d minimum area enclosing rectangle is computed for the projection of these points onto the specified projection plane. Note that the minimum area enclosing rectangle is not necessarily identical with the minimum perimeter enclosing rectangle.

Use Generate points on primitives and Generate points on solids to generate input data.

Figure 41: 2d convex hull (green), minimum area enclosing rectangle (red) and minimum perimeter enclosing rectangle (blue)

Example

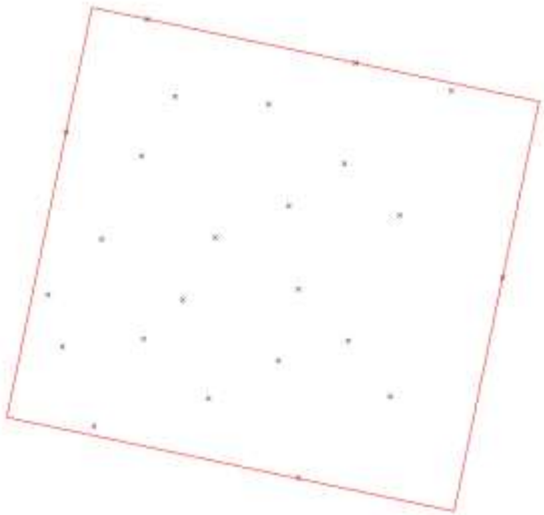


Figure 42: Minimum area enclosing rectangle of 24 points

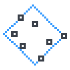
Command line prompt:

```
Minimum perimeter enclosing rectangle properties:
Width           : 682.4514
Height          : 623.1447
Area            : 425265.9925
Perimeter length: 2611.1923
```

9.3 Minimum perimeter enclosing rectangle

Compute the minimum perimeter enclosing rectangle of a point cloud in the plane.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Min. perimeter rectangle

Command entry: CC:HULL:MINPERIMETER

Dialog

`Select points:`

Select the points for which to compute the minimum perimeter enclosing rectangle.

`Specify projection direction [X/Y/Z/Ucs/2Points]:`

Select the projection direction.

<X>:	The rectangle is computed in the global YZ-plane
<Y>:	The rectangle is computed in the global XZ-plane.
<Z>:	The rectangle is computed in the global XY-plane. (default)
<Ucs>:	The rectangle is computed in the UCS XY-plane.
<2Points>:	The rectangle is computed in a user defined plane perpendicular to the projection direction. The following dialog occurs:

`Specify first point`

Select the first point of the normal vector defining the plane.

`Specify second point`

Select the second point of the normal vector defining the plane.

Notes

The 2d minimum perimeter enclosing rectangle is the rectangle that encloses all points with minimum perimeter length. If the points are 3d points, the 2d minimum area enclosing rectangle is computed for the projection of these points onto the specified projection plane.

Note that the minimum perimeter enclosing rectangle is not necessarily identical with the minimum area enclosing rectangle.

Use Generate points on primitives and Generate points on solids to generate input data.

Example

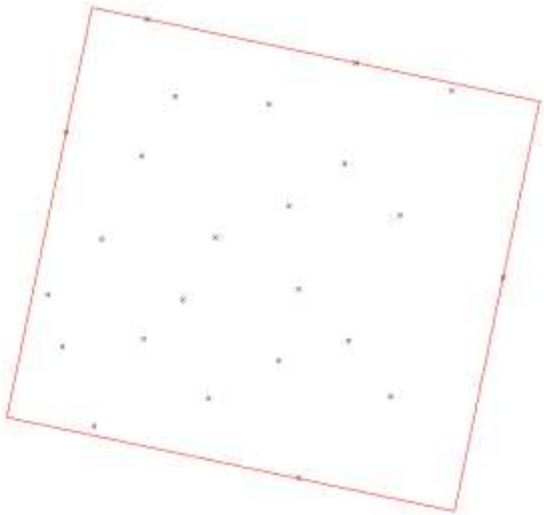


Figure 43: Minimum perimeter enclosing rectangle of 24 points

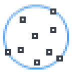
Command line prompt:

```
Minimum perimeter enclosing rectangle properties:
Width           : 682.4514
Height          : 623.1447
Area            : 425265.9925
Perimeter length: 2611.1923
```

9.4 Minimum enclosing circle

Compute the minimum enclosing circle of a point cloud in the plane.

Access methods

Toolbar: 

Menu: ComputationalCAD ➤ Min. enclosing circle

Command entry: CC:HULL:MINCIRCLE

Dialog

`Select points:`

Select the points for which to compute the minimum enclosing circle.

`Specify projection direction [X/Y/Z/Ucs/2Points]:`

Select the projection direction.

<X>:	The circle is computed in the global YZ-plane
<Y>:	The circle is computed in the global XZ-plane.
<Z>:	The circle is computed in the global XY-plane. (default)
<Ucs>:	The circle is computed in the UCS XY-plane.
<2Points>:	The circle is computed in a user defined plane perpendicular to the projection direction. The following dialog occurs:

`Specify first point`

Select the first point of the normal vector defining the plane.

`Specify second point`

Select the second point of the normal vector defining the plane.

Notes

The 2d enclosing circle is the circle that encloses all points with minimum diameter. If the points are 3d points, the 2d minimum enclosing circle is computed for the projection of these points onto the specified projection plane.

Use Generate points on primitives and Generate points on solids to generate input data.

Example

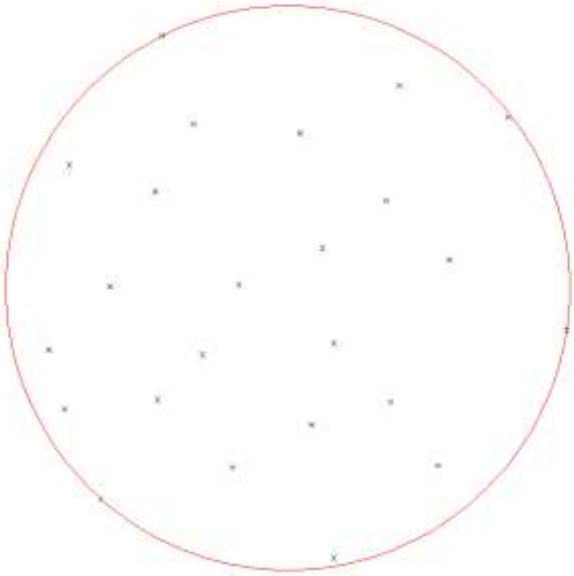


Figure 44: Minimum enclosing circle of 24 points

Command line prompt:

```
Minimum enclosing circle properties:
Radius          : 369.4109
Area            : 428715.4949
Perimeter length: 2321.0769
```

9.5 3d convex hull

Compute the 3d convex hull of a point cloud.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ 3d convex hull

Command entry: CC:HULL:3D

Dialog

`Select points:`

Select at least four non-coplanar points for which to compute the 3d convex hull.

Notes

The 3d convex hull of a set of point encloses all points with minimal surface area. The computation of the 3d convex hull requires at least four non-coplanar points (for which the convex hull is a tetrahedron then).

Use <u>Generate points on primitives</u> and <u>Generate points on solids</u> to generate input data.

Example

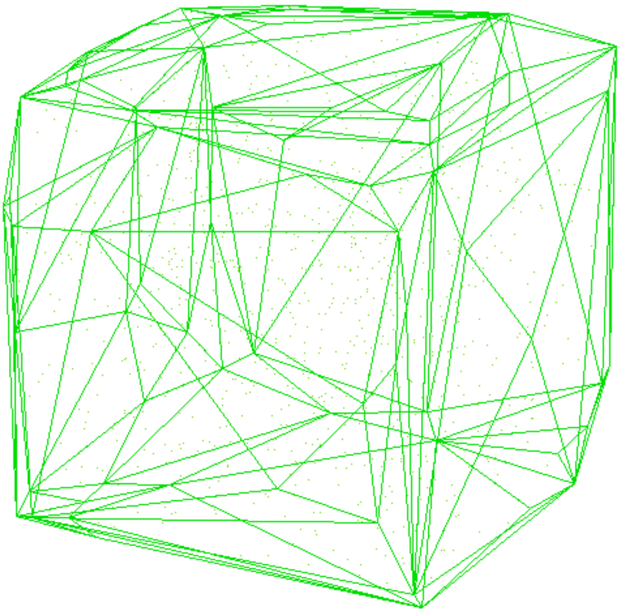


Figure 45: 3d convex hull of 1000 random points in a cube (wireframe)

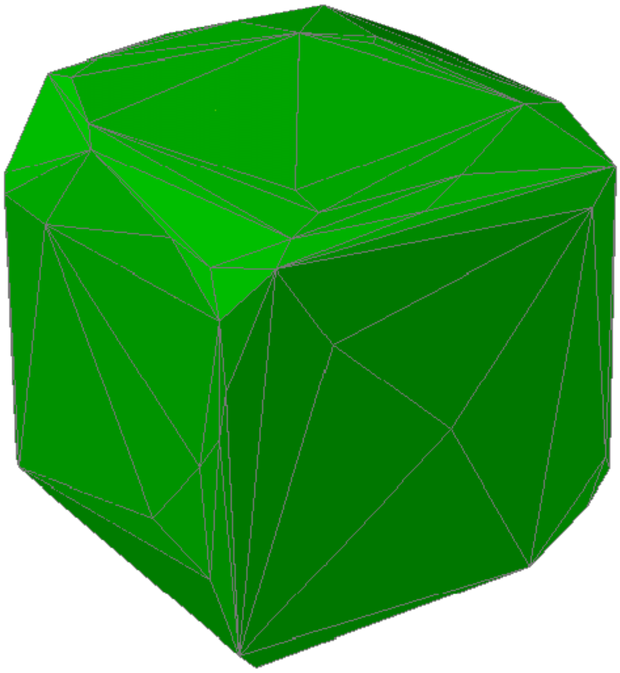


Figure 46: 3d convex hull of 1000 random point in a cube (rendered)

Command line prompt:

```
3d convex hull properties:
--------------------------
Number of vertices on hull: 140
Number of invalid vertices: 0
Number of faces on hull   : 276
Number of degenerate faces: 0
Hull surface area         : 2487444.0086
Hull volume               : 287626283.7002
Center of mass            : (2114.3216, 1094.4953, 0.0000)
```

9.6 Principal axes bounding box

Compute the principal axes bounding box of a point cloud.

Access methods

Toolbar:

Menu: ComputationalCAD ➤ Principal axes bounding box

Command entry: CC:HULL:PABB

Dialog

`Select points:`

Select at least four non-coplanar points for which to compute the principal axes bounding box.

Notes

The principal axes bounding box is the bounding box along the principal axes of inertia of the 3d convex hull of the point cloud. Along these axes, the minimum extents of the convex hull define the extents of the bounding box.

In a general case, the principal axes bounding box is a very tight bounding box of a point cloud. However, tighter bounding boxes may exist. The quality (tightness) of the principal axes bounding box is the better the more distinct the values of the mass moment of inertia are. In contrast, the principal axes bounding box may be very poor for example for a cube, which has the same mass moment of inertia about its centre for any axis.

Use Generate points on primitives and Generate points on solids to generate input data.

Example

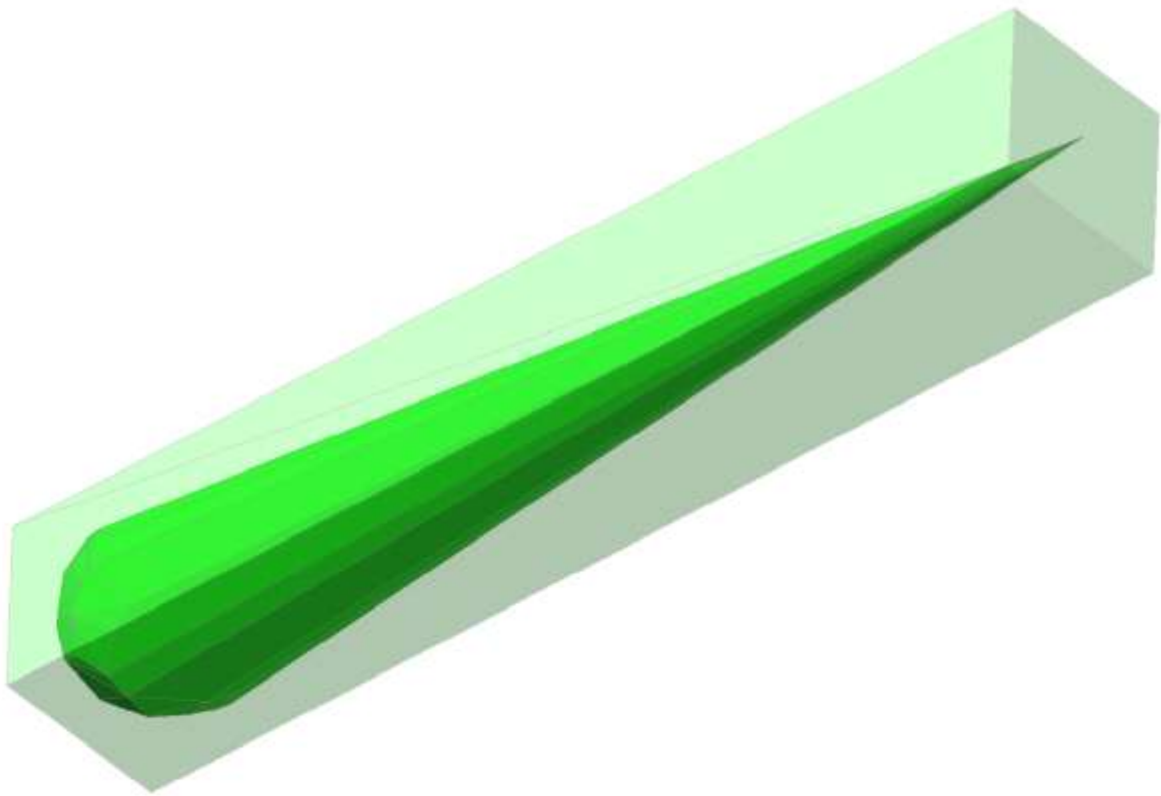


Figure 47: Principal axes bounding box and convex hull of 195 points

Command line prompt:

```
Principal axes bounding box properties:
---------------------------------------
Width              : 695.3335
Length             : 2144.3264
Height             : 730.5104
Volume             : 1089207088.4633
Center             : (2619.7359, 1095.8920, 0.0000)
First basis vector : (1.0000, 0.0000, 0.0000)
Second basis vector: (0.0000, 1.0000, 0.0000)
Third basis vector : (0.0000, 0.0000, 1.0000)
```